

Karsell Proposed Draft Update (2016-04-26) of

Annex A of Draft LEO-S-002 Standard, April 26 2016

**Life Cycle Assessment Framework for Establishing Product, Organization, and Building,
Environmental Footprints and LCAs, and Requirements for Associated Public Claims**

Annex A

(Normative)

**Procedures for Calculating
Category Indicator Results by Impact Category**

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1 **1. Introduction.**

2
3 The calculation of indicator results for each impact category is described in this Annex. This
4 process includes:

- 5
6 • Establishing the stressor-effects network for each impact category;
7 • Selection of category indicator(s) for the impact category;
8 • Establishing the environmental relevance of the selected category indicator;
9 • Determining the environmental data needed to assess the selected category indicator;
10 • Establishing characterization models to calculate Potency Potential Characterization
11 Factors (PP-CFs) and Midpoint Characterization Factors (M-CFs); and
12 • Establishing equations to calculate the category indicator.

13
14 Guidance and requirements are provided for each of these steps, for each impact category. In
15 some cases, tables of data are provided for PP-CFs whenever such data involve fundamental
16 chemical relationships not subject to further data collection.

17
18 The table below provides a list of impact groups, impact categories, and recommended category
19 indicators. Impact categories are named based upon midpoints/endpoints of the stressor-effects
20 networks. Category indicators are named based upon the characterization models which are used
21 to derive characterization factors.
22

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1
2

Table 1. The impact groups, impact categories, and recommended category indicators.

Impact Groups and Impact Categories	Recommended Category Indicator
Group 1: Biotic/Abiotic Resource Depletion Impacts	
Energy Resource Depletion	Energy Resource Depletion
Water Resource Depletion	Water Resource Depletion
Minerals and Metals Resource Depletion	Mineral/Metal Resource Consumption (by type)
Biotic Resource Depletion	Biotic Resource Consumption (by type)
Group 2: Global and Regional Climate System Impacts	
Global Climate Impacts	Global mean radiative forcing
Regional Climate “Hot Spot” Impacts	Regional radiative forcing
Group 3: Ocean Ecosystem Impacts	
Ocean Acidification	Carbonic Acid Formation
Ocean Warming	Not specified
Marine Biome Disturbance	Not specified
Marine Eutrophication	Not specified
Key Species Loss	Not specified
Persistent, Bioaccumulative, and Toxic Chemical Loading	Dependent on Chemical
Cumulative Plastic Loading	Not specified
Group 4: Terrestrial and Freshwater Ecosystem Impacts (from Emissions)	
Regional Acidification	Regional Acidification
Stratospheric Ozone Depletion (Antarctica)	Stratospheric Ozone Depletion
Freshwater Ecotoxic Exposure Risks	HEC Emissions
Freshwater Eutrophication	Eutrophication
Terrestrial Eutrophication	Not specified
Group 5: Terrestrial/Freshwater Ecosystem Impacts (from Land Use and Conversion)	
Terrestrial Biome Disturbance	Terrestrial Biome Disturbance (by biome)
Freshwater Biome Disturbance	Freshwater Biome Disturbance (by watershed)
Wetland Biome Disturbance	Wetland Biome Disturbance (by wetland)
Key Species Habitat Disturbance	Key Species Habitat Disturbance (by species)
Group 6: Human Health Impacts (from Chronic Exposure to Hazardous Chemicals)	
Ground Level Ozone Exposure Risks	Ground Level Ozone Exposure Risks
PM 2.5 Exposure Risks	PM 2.5 Exposure Risks
Ambient Air Exposures to Hazardous Chemicals	Hazardous Ambient Air Contaminant Emissions
Indoor Air Exposures to Hazardous Chemicals	Hazardous Indoor Air Contaminant Emissions
Ingestion Exposures to Hazardous Chemicals	Hazardous Food or Water Contaminant Emissions
Dermal Contaminant Exposure Risks	Dependent on contamination route

3
4
5

Section 1.1 describes in depth the selection of category indicators in each impact category.

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1 **1.1 Selection of Category Indicators.** As described in ISO 14044, the environmental relevance is a
2 qualitative assessment of the degree of linkage between category indicator result and the category
3 endpoint(s) (ISO 14044 §4.4.2.2.2). Higher levels of environmental relevance provide results which
4 have a stronger linkage to endpoints, and are therefore more desirable.

5
6 There are two aspects which determine the environmental relevance of a category indicator
7 (from ISO 14044 §4.4.2.2.4):

- 8
9 a) The ability of the category indicator to reflect consequences on category endpoint(s); and
10 b) The incorporation of environmental data into the characterization model, used to
11 represent the category endpoint(s).

12
13 The environmental relevance which can be achieved in a given impact category is limited by the
14 availability of characterization models and environmental characterization data. Proceeding
15 along the stressor-effects network for an impact category, additional aspects of the
16 environmental mechanism are incorporated into category indicator results (e.g., spatial and
17 temporal variability), which generally requires more sophisticated characterization models and
18 additional environmental characterization data.

19 **For example.** For some impact categories (i.e., Hazardous Ambient Air Exposure Risks, and
20 Hazardous Indoor Air Exposure Risks), the current lack of characterization models and/or characterization
21 data prevents establishing category indicators at higher nodes. This limits the environmental relevance
22 which can be achieved.

23
24 For other impact categories (i.e. Global Climate Change), characterization models and data exist
25 to establish results at higher nodes. However, as one proceeds along the stressor-effects network,
26 the integration of more sophisticated characterization models and additional environmental data
27 results in additional measurement uncertainty. The following discussion from *Spatial*
28 *differentiation in Life Cycle impact assessment*, published by the Danish Ministry of the
29 Environment, provides this description:

30
31 As characterization modelling is extended to include more of the causality
32 chain, the uncertainty in interpretation is typically reduced as the
33 environmental relevance of the predicted impact is increased. On the other
34 hand, the introduction of additional environmental models into the
35 calculation of characterization factors also introduces some additional
36 sources of uncertainty.

37
38 The overall uncertainty of a category indicator reflects its overall linkage to category endpoint(s).
39 The inverse of the overall uncertainty of a category indicator is its environmental relevance. A
40 category indicator with high overall uncertainty has low environmental relevance; and a category
41 indicator with low overall uncertainty has high environmental relevance.

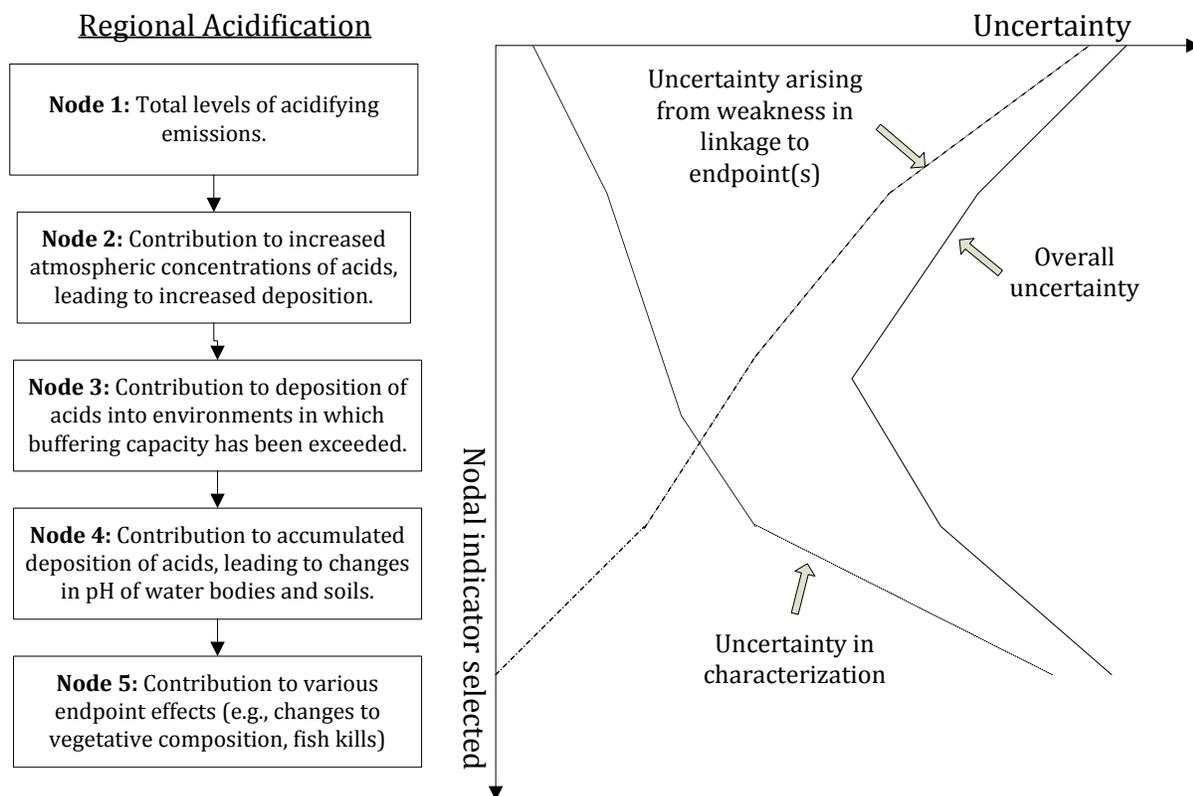
42
43 The overall uncertainty is affected by two aspects of uncertainty:

- 44
45 (1) *Uncertainty arising from weakness in the linkage to category endpoint(s).* This
46 uncertainty is based upon the ability of the category indicator to reflect consequences
47 of the LCI results on category endpoint(s).

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1 (2) *Uncertainty inherent in the characterization of category indicator results.* This arises
2 from uncertainty in the LCI results, characterization model, and environmental
3 characterization data which is used.
4

5 When considering the overall uncertainty of category indicators at different nodes in the
6 stressor-effects network for a given impact category, there is a trade-off between these two
7 sources of uncertainty. Figure 1 graphically shows this trade-off for the example of one impact
8 category: Regional Acidification.
9



10 **Figure 1. On the left, the category indicators and characterization models which could be selected for Regional Acidification**
11 **are shown. On the right, the sources of uncertainty which determine the overall uncertainty (and environmental relevance).**
12 **As characterization proceeds further along the stressor-effects network for Regional Acidification, the uncertainty arising**
13 **from weakness in linkage to endpoint(s) decreases. At the same time, additional uncertainty is introduced through**
14 **uncertainties in the characterization model, characterization data, assumptions applied, and etc. Category indicators must**
15 **be selected so that the overall uncertainty is minimized (i.e., the environmental relevance is maximized).**
16

17 Figure 1 shows that for Regional Acidification, the uncertainty arising from weakness in linkage
18 to endpoint(s) decreases as characterization proceeds further along the cause-effects chain.
19 However, the uncertainty in characterization, related in this case to uncertainty introduced from
20 dispersion modeling, and uncertainty in the environmental data which is used (i.e.,
21 meteorological data, topographical data, and etc.), increases. The category indicator is selected
22 so as to minimize the overall uncertainty, which maximizes the environmental relevance of
23 results. For Regional Acidification, the lowest overall uncertainty is at Node 3.
24

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1 The level of overall uncertainty for different category indicators differs significantly for different
2 impact categories, particularly when considering impact categories in different groups.
3 Accordingly, optimization of the trade-off between the two sources of uncertainty must be
4 determined separately for each impact category. For some impact categories, the availability of
5 environmental data varies by region, and optimization must be performed separately for
6 different LCA studies, considering the goal and scope of the study.
7

8 ***For example.*** For Ground Level Ozone Exposure Risks, ambient concentrations of ozone are unavailable in
9 some regions (i.e., in countries such as China and India). Although the recommended category indicator for
10 this impact category is at Node 4, if a study considers emission sources in China or India, environmental
11 data is unavailable to characterize results at this node. For this impact category, characterization is allowed
12 at Node 3, for which the environmental data required is available globally (i.e., the data required for
13 dispersion modeling and population density mapping).
14

15 For each impact category, this Annex provides guidance and requirements for selection of the
16 category indicator, as part of the section describing Stressor-Effects networks. The category
17 indicators which can be used are noted, and a category indicator is recommended for use which
18 has the highest environmental relevance (i.e., the category indicator where the overall
19 uncertainty is minimized). As more accurate and new levels of environmental data become
20 available, practitioners are encouraged to move to higher nodal indicators, increasing the
21 environmental relevance beyond that possible if the recommended category indicator is used.
22

23 For a given LCA study, the availability of environmental data may limit the environmental
24 relevance which can be achieved, and it may not be possible for results to be calculated using the
25 recommended indicator. For each impact category, the Annex provides further guidance and
26 requirements for the selection of category indicators in case of this lack of data availability.
27

28 For certain category indicators in certain impact categories, the overall uncertainty is so high that
29 there is effectively no environmental relevance. Use of these category indicators is not permitted
30 under this Standard.
31
32

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2 Biotic/Abiotic Resource Depletion Group.

This section describes the procedures for calculating results for those category indicators related to the consumption and depletion of resources.

Aside from energy resource depletion, which can be aggregated on the basis of energy, the aggregation of material abiotic or biotic resources into a single category indicator result is not allowed.

Definition of Renewable and Non-renewable Resources

In this Standard, nonrenewable resources are defined as those which, after being consumed, *are not completely* regenerated within the time horizon relevant to the energy resource (i.e., the total consumption must equal or exceed the total accretion of the resource with the time horizon). Renewable resources are defined as those which, after being consumed, *are completely* regenerated within the time horizon relevant to the energy resource (i.e., the total accretion must equal or exceed the total consumption of the resource within the time horizon). Similarly, nonrenewable and renewable consumption of resources is distinguished by considering if the resource is completely regenerated within the time horizon relevant to the resource.

NOTE. The defined timeframe which is used will vary based on the resource. However, this timeframe should never be longer than the century scale, based on the timeframe of LCA studies. The timeframe will be as short as 5-10 years for some types of biotic resources.

Definitions of Reserve Base Types

To understand the stressor-effects network in this group of impact categories, and for proper classification and characterization, consistent definitions of the types of “reserve base” relevant to energy resources are very helpful. In practice, there are a variety of definitions for different types of reserve bases used by different agencies, which vary by resource type.

NOTE. The US Energy Information Administration, US Geological Survey, International Energy Agency, International Atomic Energy Agency, are agencies which use different definitions of reserve bases for different resources.

For the purposes of this Standard, the following definitions are used:

- *Technically Recoverable Reserve Base.* Also referred to simply as “reserve base” in this Standard, a technically recoverable reserve base refers to that part of an identified resource reserve that could be commercially extracted at a given time. The technically recoverable reserve base meets specific minimum physical and chemical criteria related to extraction practices for the given energy resource. The technically recoverable reserve base may encompass those parts of a resource that have a reasonable potential for becoming economically recoverable within planning horizons that extend beyond those which assume

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1 proven technology and current economics.¹ For a given resource type, the technically
2 recoverable reserve base includes:

- 3 ○ *Economic reserves*, including those resources that are currently economically
4 recoverable, given current extraction technologies and market conditions.
- 5 ○ *Marginal reserves*, including those resources that are marginally economically
6 recoverable, given current extraction technologies and market conditions.
- 7 ○ *Sub-economic reserves*, including those reserves which are not economically viable
8 to recover given current extraction technologies and market conditions, but which
9 could become economically viable to recover within reasonable planning time
10 horizons.

- 11 • *Proven reserves*. These are reserves that are based on estimated quantities of an energy
12 resource, that analysis of geologic and engineering data demonstrates with reasonable
13 certainty are recoverable given current technology and current economics.²
- 14 • *Unproven reserves*. These are reserves that are yet undiscovered, but are reasonably assured
15 to exist in favorable geological settings.³
- 16 • *Speculative reserves*. These are reserves which are thought to exist, mostly on the basis of
17 indirect evidence and geological extrapolations, in resource bases which are discoverable
18 with existing exploration techniques.⁴

19 2.1 Energy Resource Depletion

20 **2.1.1 Impact Category.** The impact category characterizes the depletion of energy
21 resources which can be linked to the anthropogenic system under study. Energy resource
22 depletion considers not only energy consumption, but also the total extent of reserve bases and
23 consumption rates of the various feedstocks used for energy production, over a specific time
24 horizon. Based on the data which is commonly available regarding reserve bases and resource
25 consumption, this time horizon is usually 25 years.

26 The category indicator for this impact category accounts for both biotic and abiotic feedstocks
27 that are consumed for energy generation. Energy resource depletion only accounts for the
28 nonrenewable consumption of energy resources.
29

¹ This is based upon the definition of the Demonstrated Reserve Base for coal, used by the US Energy Information Administration See *U.S. Coal Reserves, 1996, Appendix A, Specialized Resource and Reserve Terminology*.

² This definition is based upon the definition of proved reserves of crude oil published by the US Energy Information Administration I the *International Energy Outlook*.

³ This is based upon the definition of unproven technically recoverable reserves of crude oil and natural gas, yet undiscovered, as defined by the US Energy Information Administration. It roughly parallels the definitions of inferred resources used by the OECD and International Atomic Energy Agency to describe available uranium reserves.

⁴ This is based upon the definition for Speculative Resources of uranium used by the OECD and International Atomic Energy Agency.

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1 **2.1.2. Stressor-Effects Network.** This stressor-effects network represents the depletion of
2 energy resources extracted from the providing environment, and is described in Error! Reference
3 source not found. of Annex B. The providing environment includes reserve base(s) which can be
4 at the local, regional, or global scale, depending on the characteristics of the market where the
5 energy resource is consumed. Accordingly, the midpoint of contribution to nonrenewable energy
6 resource consumption from a specific reserve base should be understood (Node 2 in Error!
7 Reference source not found. of Annex B); this is required to accurately characterize results at
8 Node 3, energy resource depletion.

9 For a specific LCA study, the data sources and definitions used to assess each type of reserve base
10 must be described in the LCA report.

11 **2.1.2.1. Selection of Category Indicator(s).** The indicator for this impact category shall be
12 characterized at Node 3, characterizing the contribution to energy resource depletion within
13 projected timeframes of interest.

14 **2.1.2.2. Identifying Core Impact Categories and Category Indicator(s).** All known
15 anthropogenic systems contribute to the non-renewable consumption of energy resources, and
16 energy resource depletion is always a relevant impact category.

17 **2.1.3. Classification.** This Standard requires all energy resources which are consumed in a non-
18 renewable fashion be included in final category indicator results. This includes all abiotic energy
19 resources that are extracted from inherently limited reserve bases. In practice, consumption of
20 hydrocarbon-based fossil fuels and uranium ore are always classified. These feedstocks are listed
21 in Table 2. 1.

22
23 **Table 2. 1. Non-renewable energy resources which are classified in Energy Resource Depletion.**

Nonrenewable Energy Resource Types
Coal
Crude oil
Natural Gas
Uranium ore

24
25 **2.1.3.1. Classification of “Renewable” Resources.** In some instances, energy resources which
26 are usually considered to be “renewable” will be classified, if the energy resource is being
27 consumed in a nonrenewable fashion. This reflects the fact that a given “renewable” energy
28 resource may not actually be consumed at a renewable rate.

29
30 An energy resource commonly thought of as renewable can be classified as non-renewable if the
31 amount of accretion of the resource is less than the amount of consumption within a specific time
32 horizon relevant to the energy resource.

33
34 For biotic resources, the time horizon used should reflect the typical planning time horizons used
35 in industry practice.

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1 FOR EXAMPLE. To be classified as renewable, the growth rate of timber at a forestry operation must exceed
2 the harvest rate of the tree species being extracted. In forestry, the growth-to-harvest ratio is typically
3 assessed as a rolling 10-year average, and renewability should be determined using a 10-year time horizon.
4

5 For a given energy resource, the timeframe used to determine the renewability shall be described
6 in the LCA report.

7 NOTE. The time horizon used to determine renewability is not necessarily the same as the time horizon
8 used in RDF calculations.

9 **2.1.3.2. Classification of Non-renewable Energy Consumption Used in Standby Power**

10 **Generation.** Some renewable energy resources are unable to provide energy as a stand-alone
11 source when deployed in the electricity grid, but rather must be combined with non-renewable
12 energy resources in order to provide a continuous source of energy.

13 FOR EXAMPLE. Due to its intermittency, wind power plants must be backed up with “standby” power
14 plants fueled by non-renewable energy resources. These standby plants must increase energy output to
15 compensate for the variability of wind resources. The consumption of non-renewable energy resources in
16 these standby plants will increase as the penetration of wind energy increases in regional electricity grids.
17

18 If renewable energy resources which are intermittent are included in the scope of the LCA study,
19 the consumption of non-renewable energy resources at the standby power plants must be
20 classified. This will affect results for other impact categories, for which there are stressor effects
21 networks linked to consumption of non-renewable energy resources at standby power plants.

22 **2.1.4. Characterization**

23 **2.1.4.1. Potency Potential Characterization Factor.** The PP-CF is the energy content of the
24 each energy resource classified in the study, in units of Gigajoules of energy per unit of
25 feedstock.

26
27 When assessing results for a category indicator, the same definitions of the energy content must
28 be used. If the higher heating value is used as the basis of the PP-CF for one feedstock (e.g., coal),
29 the higher heating value must also be used for all other relevant feedstocks (e.g., natural gas and
30 crude oil).

31 NOTE. To assess the energy content of fuels which are combusted to generate energy, the higher heating
32 value is more commonly used. This Standard recommends the use of the higher heating value to assess the
33 energy content of combustible fuels.
34

35 The data sources used as the basis of PP-CFs shall be described in the LCA report. The following
36 characteristics should be taken into account in calculating the PP-CF:

- 37
- The type of feedstock considered.

38

 - The data source used to derive the energy content.

39

 - The region in which the feedstock is produced.

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- 1 • The grade of the feedstock (e.g., the coal assay).
- 2 • The volumetric density of the feedstock.
- 3 • For energy resources which are combusted to generate energy, whether the energy content
- 4 is based upon the higher or lower heating value.
- 5 • Any other characteristics which could influence the value of the PP-CF for a specific energy
- 6 resource.

7 The use of generic data for the energy content of specific feedstocks can be used in the first
8 iteration, to determine the elementary flows which are the main contributors to final results in
9 this impact category; however, in the second iteration, the characteristics above should be
10 integrated into PP-CF calculations. If data is unavailable for any of these characteristics, the effect
11 on final results should be considered, in the context of the goal and scope of the study. Sensitivity
12 analysis is a useful tool to determine the significance to final results of differences in possible PP-
13 CFs which could be used.

14
15 If a characteristic used to determine PP-CF values is found to have a strong effect on final results,
16 but no specific data is available to accurately assess the PP-CF, it may not be possible to achieve
17 the goals of the study. In these cases, the goal and/or scope may need to be revised.

18 **2.1.4.2. Midpoint Characterization Factors.** The M-CF for each energy resource is the
19 resource depletion factor (RDF). The RDF is a unitless factor, which considers the net
20 consumption (accounting for any accretion which may occur) by all users of the technically
21 recoverable reserve base of that resource, over a specific time horizon. The RDF is calculated
22 using Equation 2.1 for a given energy resource, factoring in total consumption, total accretion (if
23 applicable), and the reserve base extent.

24
25 **Equation 2.1. Equation for calculating the Resource Depletion Factor (RDF), for a given energy resource over a specific**
26 **time horizon for Energy Resource Depletion.**

$$RDF_{TH} = (Consumption_{TH} - Accretion_{TH}) / Reserve Base_{TH}$$

Where

- *TH = Time Horizon (usually 25 years)*
- *RDF = Resource depletion factor for a specific energy resource type.*
- *Reserve base is the technically recoverable reserves for the given energy resource in a given market.*
- *Consumption, accretion, and reserve base all measured in units of mass or energy, depending upon the energy resource, and are evaluated over TH.*

27
28 For most energy resources, a 25 year time horizon is used to calculate the RDF, because this
29 timeframe reflects a reasonable planning period for energy producers, and because the
30 uncertainty of the reserve bases, consumption and accretion levels is relatively low.

31 NOTE. Many governmental and international organizations (such as the US Energy Information
32 Administration) provide estimates of projected consumption on multiple time horizons, up to 25 years.

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2.1.4.2.1. Assessing Total Consumption and Extent of Reserve Base of an Energy

Resource. In assessing the RDF for a given energy resource, the regional market conditions which are relevant must be understood. The source region and grade of an energy resource feedstock must be understood, in order to understand the relevant consumption estimates and reserve bases for use in RDF calculations. In many markets, regional consumption and reserve base estimates should be used. Reserve base and consumption estimates can also vary based on the grade of the non-renewable energy feedstock which is considered.

FOR EXAMPLE. In the United States, between 90-99% of coal and natural gas consumed will be produced domestically over the next 25 years. However, a significant fraction of the oil and uranium consumed in the United States comes from global suppliers, including suppliers from Africa and the Middle East. For a unit process located in the United States, when assessing the RDF for coal and natural gas, data based on consumption and reserve bases of these resources in the United States is appropriate, while RDFs for crude oil and uranium should be based on global data.

For the major non-renewable energy feedstocks (i.e., coal, crude oil, natural gas, and uranium), national and international agencies provide data on projections of consumption of fuels over specific time horizons, usually up to 25 years. Different data sources can provide different estimates on overall consumption; the data source used as the basis of consumption values used in RDF calculations shall be described in the LCA report. Sensitivity analysis can help to understand the significance to final results on the data sources used.

The RDF should be based upon the best estimate for the relevant technically recoverable reserve base. This reserve base can be regional, or global. Proven reserves of all relevant non-renewable energy resources shall be included in the reserve base estimate. Unproven reserves shall also be included in the reserve base estimate, provided that the expected uncertainty in the extent of unproven reserves is less than the expected bias introduced through the omission of the unproven reserves.

For the major non-renewable energy feedstocks (i.e., coal, crude oil, natural gas, and uranium), national and international agencies provide data on the reserve bases according to several different definitions. The reserve bases definitions used vary between resource types, and between agencies; these definitions, as well as the correlations between different terms and data, should be understood, to ensure that data is correctly interpreted and integrated into RDF calculations.

In the LCA report, all data sources used in the RDF calculation shall be described, as well as the reserve base definitions used.

To estimate the depletion of renewable energy resources that are consumed at a nonrenewable rate (i.e., consumption in excess of accretion), site-specific data must be obtained on the consumption and accretion of the specific reserve in question.

FOR EXAMPLE. Geothermal energy resources can be consumed at a non-renewable rate. The specific lengths of time that geothermal reservoirs maintain their useful commercial heat transfer are well established and can be obtained from operators of the geothermal units.

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1 **2.1.5. Indicator Equation and Unit of Measure.** The indicator equation for calculating energy
2 resource depletion for a single unit process is shown in Equation 2.2. For this category indicator,
3 the unit of measure is expressed in units of energy equivalents (e.g., Gigajoule equivalents). As
4 this is an accumulated midpoint, the indicator result is calculated as an accumulation over the
5 total number of years in the LCA time horizon.

6
7 **Equation 2.2. Indicator equation for Energy Resource Depletion for a single unit process.**

Energy Resource Depletion =

$$\sum_j \sum_n (\text{Non-renewable Energy Resource Consumption in year } j \\ \times \text{PP-CF}_n \times \text{RDF}_n)$$

Where:

- *j represents the total number of years in the LCA time horizon (for this accumulated midpoint)*
- *n represents the total number of types of energy resources consumed by a unit process*
- *PP-CF is the equivalent energy content between energy resources*
- *RDF is the resource depletion factor*

8
9 **2.1.6. Additional Reporting Requirements.** There are no additional reporting requirements for
10 this impact category.

11 **2.1.7. Addressing Additional Limitations in the Types, Accuracy and Availability of**
12 **Environmental Data.** The critical environmental data are the estimation of the reserve bases for
13 different resources, and the projected consumption of these resources over time. While most
14 energy sources rely on global reserves and are traded on a global basis, others are regional in
15 nature, depending on the energy resources in question, the location, and the market factors
16 associated with the product or system. It is recommended that official government estimates of
17 energy reserves serve as the default environmental data for the major energy resources.

18 **2.2. Water Resource Depletion**

19 **2.2.1. Impact Category.** The impact category represents the depletion of water supplies in the
20 providing environment (i.e., in hydrological reserves) linked to the anthropogenic system under
21 study. Hydrological reserves include, but are not limited to, surface waters supplies, reservoirs
22 of potable water, and groundwater aquifers.

23 **2.2.2. Stressor-Effects Network.** The stressor-effects network may contain stressors,
24 midpoints, and endpoints for water resource depletion which are distinct for different unit
25 processes in the anthropogenic system under study. The stressor effects network shown in Error!
26 Reference source not found.2 of Annex B generally describes the nodes in the cause-effects chain;
27 however, the scale, severity, and reversibility of midpoints can vary significantly for different
28 affected hydrological reserves, based upon considerations such as: the total net water

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1 withdrawals from the reserve, by all users; the replenishment rates of the hydrological reserve;
2 the extent of the hydrological reserve; and other considerations.

3
4 In the first iteration, the net water consumption should be assessed; unit processes which are
5 major contributors to net water consumption should be identified. The relevant hydrological
6 reserve(s) from which these unit processes obtain water should be identified. The stressor effects
7 networks should initially be modeled separately for each of these hydrological reserve(s). This
8 will greatly aid in classification and characterization.

9 **2.2.2.1. Selection of Category Indicator(s).** The category indicator should be at Node 2,
10 characterizing the contribution to total net water consumption, in hydrological reserves where
11 total net withdrawals are a significant fraction of replenishment rates (see Error! Reference
12 source not found.).

13
14 If data is unavailable for characterization at Node 2, characterization is at Node 1. This
15 characterizes the net water consumption of unit processes in the anthropogenic system under
16 study. Characterization at Node 1 has low environmental relevance.

17 **2.2.2.2. Identifying Core Impact Categories and Category Indicator(s).** Water resource
18 depletion is a relevant impact category only in cases where net water consumption at a unit
19 process is contributing to total net withdrawals which are a significant fraction of total
20 replenishment rates for the affected hydrological reserve(s).

21
22 To minimize data collection requirements, in the first iteration, the main contributors to net
23 water consumption (the Node 1 result) should be assessed. At those unit processes which are
24 main contributors to this result, the hydrological reserves from which water is withdrawn should
25 then be identified.

26
27 For a given unit process, water resource depletion can be excluded as a core impact category if
28 the total net water withdrawals by all users from the relevant hydrological reserve is negligible
29 compared to the replenishment rate. This comparison of net withdrawals to replenishment can
30 be assessed using direct measurements of net withdrawals and replenishment, or by other
31 considerations (e.g., assessing economic conditions in water supplies in this region).

32 FOR EXAMPLE. At a unit process in Humboldt County, net water consumption is occurring, with water
33 being diverted from surface water supplies. However, due to a surplus of surface water supplies in
34 Humboldt County, the regional water supply agency is attempting to sell exported water. Water resource
35 depletion is excluded as relevant for this unit process, as net withdrawals are negligible compared to the
36 replenishment rate of surface water supplies.

37 FOR EXAMPLE. Desalination, where saline water is withdrawn from oceans and treated to generate potable
38 water, contributes to net water consumption. However, the annual replenishment rate of the world's
39 oceans is far in excess of total net withdrawals by all users. Net withdrawals of ocean water will not
40 contribute to water resource depletion.

41
42 In some cases, data will be unavailable regarding conditions in relevant hydrological reserves
43 linked to net water consumption in the anthropogenic system. The effect on final results of this
44 lack of data should be considered in the content of the goal and scope of the LCA study. A

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1 sensitivity analysis can help to understand the significance of including or excluding net water
2 consumption at unit process(es) affecting this hydrological reserve. If the effect of inclusion or
3 exclusion on final results is significant, results may need to be characterized at Node 1, reporting
4 net water consumption. If the effect of inclusion or exclusion is within the expected confidence
5 interval of results estimated from an analysis of uncertainty for the other unit processes,
6 simplifying assumptions can be made regarding inclusion or exclusion.

7
8 If water resource depletion is excluded as a relevant impact category, the justification for the
9 exclusion shall be provided in the LCA report.

10 **2.2.3. Classification.** In general, net water consumption is classified. This accounts for the
11 amount of a water withdrawal which is not returned to their original source. Net water
12 consumption can include:

- 13 • Water which is withdrawn from a hydrological reserve, but returned to another (e.g., water
14 pumped from a groundwater aquifer, but returned to a surface water supply in a different
15 hydrological reserve).
- 16 • Water which is withdrawn and subsequently evaporated.
- 17 • Water which is withdrawn and then incorporated into products or co-products.
- 18 • Water which is withdrawn and then incorporated into waste products (e.g., water used and
19 stored in treated wastes).

20 When using secondary inventory data, care should be taken that flows of net water consumption
21 are properly classified. In the first iteration, a validation of data regarding water use across the
22 anthropogenic system under study should be conducted, checking that unit processes which are
23 known to be significant net consumers of water (i.e., thermal power plants and agriculture in
24 certain regions) are in fact, accounted for in the LCI analysis as contributing to net water
25 consumption.

26
27 Unit process(es) which are major contributors to results for net water consumption, but have
28 high levels of variability in net water consumption (e.g., agriculture) should also be identified; the
29 use of secondary data to model net water consumption at these unit processes can introduce
30 uncertainty in results. This introduced uncertainty should be considered in the context of the goal
31 and scope of the LCA study.

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1 **2.2.4. Characterization**

2 **2.2.4.1. Potency Potential Characterization Factor.** There are no equivalencies in this
3 impact category. The PP-CF is equal to one.

4 **2.2.4.2. Midpoint Characterization Factor.** The M-CF for all extracted water resources is the
5 resource depletion factor (RDF), which is assessed separately for each affected hydrological
6 reserve. The RDF characterizes the total net water withdrawals by all users from the
7 hydrological reserve, compared to total replenishment of the hydrological reserve, assessed
8 over a specific time horizon.⁵ The RDF for water resource depletion is calculated using Equation
9 2.3.

10 **Equation 2.3. Equation for calculating the Resource Depletion Factor, for a given hydrological reserve over a specific time**
11 **horizon, for Water Resource Depletion.**

$$RDF_{TH} = \text{Withdrawals}_{TH} / \text{Replenishment}_{TH}$$

Where:

RDF_{TH} is the Resource Depletion Factor, evaluated over a specified time horizon

- *Withdrawals_{TH} is the total net water withdrawals from the hydrological reserve, by all users, over the specified time horizon.*
- *Replenishment_{TH} is the total water replenishment of the hydrological reserve, over the specified time horizon.*

12 The time horizon used in most cases should be one year, representing an annual average of total
13 net withdrawals compared to total replenishment.

14
15 The data sources used in RDF calculations should be carefully chosen, considering the data source
16 and year of the data. For all hydrological reserves, replenishment rates (which are driven by
17 weather patterns), will fluctuate over time; the level of total net water withdrawals will also vary,
18 as a result of economic and ecosystem conditions. The scale of this variability will depend upon
19 the hydrological reserve.

20
21 In most cases, it is recommended that the RDF be calculated using data from multiple time
22 periods, to capture the variability and uncertainty inherent in the balance between net
23 withdrawals and replenishment of hydrological reserves. The data sources and calculation steps
24 used to calculate RDFs shall be described in the LCA report.

25
26 There is always uncertainty inherent in the calculation of the RDF, which is linked to inherent
27 variability in the ratio of net withdrawals to replenishment. The level of uncertainty can vary
28 considerably for RDFs assessed for different hydrological reserves. This uncertainty should be
29 considered in the context of the effect on final results, and the goal and scope of the LCA study.
30 More complex analyses and data collection should be focused on RDFs applied to net water
31 consumption for unit processes that are major contributors to final indicator results, taking the
32 goal and scope of the LCA study into consideration.

33 NOTE. In rare cases, the total net withdrawals will exceed replenishment rates for a specific hydrological
34 reserve. This results in a drawdown over time in water available in the hydrological reserve. This can occur,

⁵ This RDF is equivalent to the criticality ratio.

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1 for example, when groundwater aquifers are being pumped in excess of natural replenishment rates. In
2 these cases, following Equation 2.3, the RDF will be greater than one.

3 **2.2.5. Indicator Equation and Unit of Measure.** The indicator equation for calculating water
4 resource depletion for a single unit process is shown in Equation 2.4. For this category indicator,
5 the unit of measure is expressed in units of volume equivalents of water.

6 **Equation 2.4. Indicator equation for Water Resource Depletion for a single unit process.**

Water Resource Depletion
= Net Water Consumption x RDF

Where:

- *Water Resource Depletion is the indicator result, for a single unit process.*
- *Net Water Consumption is the net water consumption for the unit process.*
- *RDF is the resource depletion factor.*

7 **2.2.6. Additional Reporting Requirements.** If there is a significant amount of uncertainty in
8 calculation of RDFs, particularly for key unit processes, a confidence interval can be reported for
9 indicator results.

10 **2.2.7. Addressing Additional Limitations in the Types, Accuracy and Availability of**
11 **Environmental Data.** For a single hydrological reserve, the two types of environmental data
12 required to calculate the RDF for this category indicator are the total net water withdrawals and
13 total replenishment, over a specific time horizon. Groundwater reserves usually have historic
14 records on total hydrological levels as well as current drawdowns, which can help in the
15 calculation of RDFs. Surface water supplies tend to exhibit more variability, due to complicated
16 variations in annual rainfall; multi-year averages should be used to establish RDFs. Lakes also
17 are subject to variations in annual and decadal rainfall patterns and require multi-year averaging.

18
19 **2.3. Minerals and Metals Resource Depletion**

20 **2.3.1. Impact Category.** The impact category reflects the net consumption of mineral and metals
21 linked to unit process(es) in the anthropogenic system under study, for which total supplies are
22 projected to be scarce within reasonable planning timeframes. Recycling of a given mineral or
23 metal should be factored into calculations of net consumption at the end-of-life.

24 **2.3.2. Stressor-Effects Network.** This stressor-effects network represents the depletion of a
25 mineral or metal resource extracted from the providing environment, and is described in Error!
26 Reference source not found.3 of Annex B.

27 The providing environment includes reserve base(s) which vary based on the mineral or metal
28 resource, and can be at the local, regional, or global scale, depending on the characteristics of the
29 market where the resource is consumed. The midpoint of contribution to overall mineral or metal
30 resource consumption from a specific reserve base should be understood (Node 2 in **Error!**
31 **Reference source not found.**3 of Annex B), to understand the relevance of consumption of the
32 mineral or metal resource.

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1
2 For certain resources, due to large deposits of the mineral or metal and high recycling rates, the
3 extent of technically recoverable reserves are essentially unlimited within reasonable planning
4 timeframes. Consumption of these resources are not considered relevant in this impact category
5 (see Section 2.3.2.2).

6
7 In this impact category, the technically recoverable reserve base includes primary reserves, as
8 well as secondary reserves which exist in products in use.

9 **2.3.2.1. Selection of Category Indicator(s).** For each instance of net consumption of a mineral
10 or metal resource, distinct category indicators shall be defined, if the stressor-effects network
11 related to the depletion of each resource is distinct.

12 Characterization is at Node 2, the net consumption of a mineral or metal resource. Due to the
13 uncertainty in estimates of technically recoverable reserve bases, and projections of
14 consumption of minerals and metals, data is not sufficient to establish results past Node 2.

15 **2.3.2.2. Identifying Core Impact Categories and Category Indicator(s).** Net consumption of
16 a given mineral or metal resource in the anthropogenic system is a relevant impact category
17 only if the material considered could have limited technically recoverable reserve bases within
18 reasonable planning timeframes, as a result of net consumption by all users.

19 FOR EXAMPLE. In a anthropogenic system, net consumption of magnesium is occurring. Considering
20 current consumption rates by all users and the extent of technically recoverable reserves of magnesium
21 according to the United States Geological Survey, there are over 400 years of magnesium (in magnesite
22 ore) remaining. The technically recoverable reserve base for magnesium will not be limited in any
23 reasonable planning timeframe, and consumption of magnesium is excluded as relevant as an impact
24 category.

25
26 For certain resources, due to high recycling rates, large deposits of the mineral or metal, and/or
27 large secondary reserves existing in products in use, the extent of technically recoverable
28 reserves are essentially unlimited within any planning timeframe. Consumption of these
29 resources are not relevant in this impact category.

30 FOR EXAMPLE. Materials such as iron have high recycling rates, ameliorating net consumption.
31 Furthermore, there are substantial secondary reserves of steel in products in use, and iron is a substantial
32 component of the Earth's crust. For iron, the extent of technically recoverable reserves are, in practice,
33 unlimited. Net consumption of iron is not relevant to this impact category.

34
35 To identify materials where this is a relevant impact category, a screening of the net consumption
36 of all minerals and metals in the anthropogenic system should first be conducted. In this
37 screening, results should be assessed using a scale of functional unit which is conservatively
38 large.

39
40 Once results for net consumption of all minerals and metals are assessed in this screening,
41 previous experience and general knowledge should be used to exclude those minerals and metals
42 for which technically recoverable reserves will not be limited within reasonable planning
43 timeframes. This will lead to a set of indicator results for several minerals and metals resources
44 experiencing net consumption, for which supplies could be limited within reasonable planning
45 timeframes.

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1
2 A category indicator for a given mineral or metal resource can be excluded as relevant if the scale
3 of the indicator result is negligible, when compared to the estimates of the relevant technically
4 recoverable reserve base.

5
6 In the LCA report, any net consumption of minerals or metals which are excluded as relevant
7 should be described, and the basis of the exclusion shall be provided.

8 **2.3.3. Classification.** Metals and minerals that are not considered inexhaustible (e.g. sand) and
9 have limited technically recoverable reserve bases within reasonable planning timeframes are
10 classified under this impact category, according to the requirements of Section 2.3.2.1 and 2.3.2.2.
11 At a given unit process, only *net* consumption of a mineral or metal from its technically
12 recoverable reserve base is classified, considering recycling which may occur at end-of-life.

13
14 Aggregation of different metals and minerals into a single category indicator is not permitted.
15 Each mineral or metal is reported under a separate category indicator.

16
17 A given material may be extracted from several different types of ore. Consumption of all ores
18 containing a single material should be classified into the single relevant category indicator.

19 In some instances, multiple materials are extracted from the same ore; in these instances,
20 consumption of multiple material co-products may be classified into multiple category indicators.

21 FOR EXAMPLE. Lead and zinc are often co-produced during mining and refining, as these two materials
22 commonly occur in the same type of geologic deposits. The net consumption of lead and zinc from a single
23 ore should be considered for classification into separate category indicators for lead consumption and zinc
24 consumption.

25
26 At end-of-life, recycling of a mineral or metal should be classified as a negative contribution to
27 consumption, if the material can be re-processed into a quality which is identical to virgin
28 feedstock in the next product life cycle. However, for products with long useful lifetimes, care
29 should be taken when including recycling at end-of-life into indicator calculations. Use of current
30 data regarding recycling rates and processing techniques to model end-of-life processes far in the
31 future introduces significant uncertainty into indicator results; this uncertainty should be
32 considered in the context of the goal and scope of the LCA study. If the uncertainty which is
33 introduced is significant, it may not be possible to achieve the goal of the LCA study, and the goal
34 and/or scope may need to be revised.

35 **2.3.4. Characterization**

36 **2.3.4.1. Potency Potential Characterization Factor.** For each category indicator, the PP-CF
37 represents the mass of the relevant mineral or metal per mass of classified flow. The mass of an
38 inventory flow multiplied with the PP-CF gives results in units of mass of the mineral or metal
39 which is considered in the category indicator.

40 FOR EXAMPLE. In regions of the Eastern United States where zinc is produced, zinc is typically extracted
41 from carbonate hosted ores. In these ores, zinc occurs with copper, silver, and barite, with host rocks of
42 limestone and dolomite. In deposits like this, zinc content is typically roughly 5%. The PP-CF relevant for
43 zinc consumption, applied to the total mass of this carbonate hosted ore, is 0.05, representing the zinc
44 content of the ore.

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1
2 Because each mineral or metal covered under this impact category is accounted for separately,
3 there is no need to establish a resource equivalencies between materials.

4 **2.3.4.2. Midpoint Characterization Factor.** Due to the uncertainty in estimates of technically
5 recoverable reserve bases, and projections of consumption of minerals and metals, data is not
6 sufficient to establish results past Node 2, which characterizes net consumption of minerals and
7 metals (see Section 2.3.2.1). There is no M-CF.

8 **2.3.5. Indicator Equation and Units of Measure.** The indicator equation for calculating mineral
9 and metal resource depletion is shown in Equation 2.5. The reported unit of measure of the
10 indicator result is expressed in mass of mineral or metal which is consumed. As this is an
11 accumulated midpoint, the indicator result is calculated as an accumulation over the total
12 number of years in the LCA time horizon.

13 **Equation 2.5. Indicator equation for mineral or metal resource consumption, for a single material, for a single unit**
14 **process.**

$$\text{Net Mineral or Metal Resource Consumption} = \sum_j \sum_i (\text{Net Material Consumption in year } j \times \text{PP-CF})$$

Where:

- *Net material consumption is the mass of flow which is classified in the category indicator*
- *PP-CF is the Potency Potential Characterization Factor, characterizing the mass of mineral or metal per mass of flow which is classified.*
- *j represents the total number of years in the LCA time horizon (for this accumulated midpoint)*
- *i represents the total number of flows classified in the category indicator (for cases where multiple ore types are classified into this category indicator)*

15 **2.3.6. Additional Reporting Requirements.** In LCA reports and EPDs or C-EPDs, for relevant
16 category indicators, it can be informative to provide data on the current consumption rates from all
17 users and the extent of technically recoverable reserve bases. Discussion could be provided
18 regarding when drawdowns of a given material resource could become significant.

19 **2.3.7. Addressing Additional Limitations in the Types, Accuracy and Availability of**
20 **Environmental Data.** The two most important pieces of environmental data are information on
21 the projected consumption of a mineral or metal by all users, and the existing technically
22 recoverable reserves. These data are generally available in published literature. Assessments can
23 be based upon official government estimates, such as those provided by the United States
24 Geological Survey. Limitations in the data which is used should be documented in the LCA report.

25 Additional environmental data which are useful include: 1) whether the relevant reserve base is
26 regional or global in nature; 2) the size of the potential global reserve base; and 3) published
27 projections of recycling and reclamation rates. Limitations in the data which is used should be
28 documented in the LCA report, provided it has relevance to final results.

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1 **2.4. Biotic Resource Depletion (by type)**

2 **2.4.1. Impact Category.** This impact category includes the net depletion of biotic natural
3 resources (e.g., wood), that are normally considered renewable, but that in practice have been
4 found to be depleted due to an imbalance between consumption and replenishment rates.

5 This category takes into account local conditions, the rate of consumption, and the rate of
6 regrowth of biotic resources. This impact category considers only biotic resources not used for
7 energy production.

8 **2.4.2. Stressor-Effects Network.** The stressor-effects network for biotic resource depletion can
9 vary broadly. Stressors can be related to activities at unit process(es) considered in the
10 anthropogenic system under study, as well as to unit processes outside the scope of the LCA.

11 The stressor-effects network for biotic resource depletion shown in **Error! Reference source**
12 **not found.**⁴ of Annex B provides a general framework; however, separate stressor-effects
13 networks should be modeled and described for each separate indicator for biotic resource
14 depletion identified within the study scope according to the requirements of Sections 2.4.2.1 and
15 2.4.2.2. The specific stressor-effects network should describe the site-specific circumstances of
16 stressors, midpoints, and endpoints, in the cause-effect relationship in the biotic reserve base
17 under study. This should consider the past history of resource management affecting the biotic
18 reserve base, current management practices, and other considerations relevant to the
19 environmental mechanism. This detailed modeling of the stressor-effects network will greatly
20 aid in the characterization of each category indicator.

21
22 Biotic resource depletion is nearly always linked to impact categories in the Land Use Ecological
23 Impacts group, as disturbances to biomes nearly always occur in conjunction with drawdowns in
24 available biotic reserves. If impacts are found to be relevant in the Land Use Ecological Impacts
25 group, the stressor-effects network of various disturbances should be explored, to understand if
26 biotic resource depletion is occurring, as well.

27 **2.4.2.1. Selection of Category Indicator(s).** Separate category indicators shall be reported for
28 each distinct biotic resource affected by unit process(es) within the anthropogenic system
29 under study. Biotic resource depletion is distinguished into separate category indicators by
30 functional characteristics of the end products in use, not by biological or ecological
31 characteristics of the resource (e.g., by species type).

32 Care should be taken in distinguishing the multiple category indicators for biotic resource
33 depletion. To aggregate multiple biotic resources into a single category indicator, the following
34 requirements must be met:

- 35
- 36 • The function(s) of the products, and well as the function(s) of any co-products, must be similar.
 - 37 • The functional performance of the products and co-products in use must be similar. If the
38 performance is significantly different for any products or co-products (e.g., leading to
39 significantly longer product longevity or durability), aggregation may be inappropriate.
 - 40 • There must be data available for aggregation. Aggregation into a single category indicator is
41 only possible if PP-CFs can be established (see Section 2.4.4.1).

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- 1 • The characterization model for each indicator of biotic resource depletion must be distinct.
- 2 • The relative scarcity of the biotic resources must be similar. Although separate biotic
- 3 resources may be used for similar functions, if the one is much scarcer than another,
- 4 aggregation may be inappropriate.

5 The basis of aggregation between multiple biotic resources shall be described in the LCA report.

6 The function(s) of the products and co-product(s) for biotic resources considered in a given

7 category indicator shall be described in the LCA report and should be described in EPDs or C-

8 EPDs.

9

10 Characterization shall be at Node 3, characterizing the extent of drawdown in biotic resource

11 availability, if data is available. For a given biotic resource, data may be unavailable for

12 characterization at Node 3, and results instead must be reported at Node 1 or 2. The basis of the

13 characterization model and data sources which are used must be described in the LCA report.

14 **2.4.2.2. Identifying Core Impact Categories and Category Indicator(s).** While biotic

15 resources are often assumed to be inherently renewable, this depends on the regrowth rate of

16 the biotic resource, the rate of harvest, and the past history of resource management in the

17 region under study. If activities associated with a unit process lead to rates of consumption

18 exceeding the rate of regrowth for a given biotic resource, the unit process will be contributing

19 to the drawdown in the biotic reserve base, and this impact category is relevant. However, even

20 in regions where current harvests are less than regrowth rates, biotic resource depletion may

21 be relevant if the past history of resource management has led to a drawdown in biotic

22 resources, as these resources can take a significant amount of time to recover.

23 FOR EXAMPLE. At a forestry operation in North America, past forest management removed over 60% of

24 the standing stock of timber, leading to biotic (timber) resource depletion. The current forest operator is

25 harvesting timber at a rate in the forest that is much less than the regrowth rate. By doing so, the operator

26 is recovering the standing timber stocks in the forest, and reducing the result for timber resource depletion.

27 However, biotic resource depletion is still relevant, as a result of past forest management.

28

29 Due to the data collection and analysis requirements to characterize category indicators for biotic

30 resource depletion, the anthropogenic system under study should be screened to identify those

31 unit process(es) which are contributing to biotic resource depletion. This screening should be

32 intended to minimize the amount of data collection required.

33

34 For a given unit process, this impact category can be ruled out as a relevant if there is no

35 measurable contribution to any environmental mechanism of biotic resource depletion. For a

36 given unit process, the following guidance can be used to exclude biotic resource depletion as

37 relevant:

- 38 • If the anthropogenic system under study were to halt all activity, and all relevant
- 39 intermediate flows throughout the entire anthropogenic system were likewise stopped, no
- 40 measurable change in the stressors, midpoints, or endpoints of biotic resource depletion
- 41 would be observed.

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- 1 • If it can be demonstrated through observation that the activities at the unit process do not
2 contribute to a measurable drawdown in the availability of biotic resources at any location.

3 When conducting this screening, it is important to identify any types of unit process(es) in the
4 anthropogenic system which have been known in the past to contribute measurably to biotic
5 resource depletion. This includes land-intensive production activities, such as forestry.

6
7 When screening to determine if biotic resource depletion is a core impact category, the scale of
8 the functional unit used shall be large enough to include observed instances of biotic resource
9 depletion. The functional unit must not be set arbitrarily low, which could rule out this impact
10 category even in cases where biotic resource depletion is occurring and can be linked to a unit
11 process. This screening may require sensitivity analysis.

12 **2.4.3. Classification.** In this category indicator, the historic extent of the biotic reserve base is
13 classified for each relevant instance of biotic resource depletion identified according to Section
14 2.4.2.2. (Classification may entail delineation of distinct historic reserve bases into separate
15 category indicators, based upon the requirements of Section 2.4.2.1.)

16 The “historic reserve base” is intended to represent the historic condition of the biotic reserve
17 base. This historic reserve base should be established using historic data, if it is available.

18
19 In most cases, historic data will be unavailable, and reference reserve bases must be identified,
20 which represent the historic reserve base. Monitoring data evaluating the extent of the reference
21 reserve base through direct measurement is required. The reference reserve base should be a
22 reserve base which has not been affected by anthropogenic activities, with similar ecological
23 characteristics to the biotic reserve base affected by the unit process under study, considering
24 characteristics such as:

- 25 • The regional biome (see definitions in Section 6.1, 6.2, and 6.3).
- 26 • The climate, topography, hydrology, and other physical characteristics.
- 27 • The species which compose the reserve bases. (Reserves with significantly different species
28 composition are not suitable for use as a reference reserve base.)

29 In practice, there will rarely be a reference reserve base for which data is available which has not
30 been affected by anthropogenic activities. Even reference reserve bases based on primary-
31 growth reference areas in extremely remote regions never affected by any resource extraction
32 are still affected by anthropogenic climate change. Therefore, the selection of the reference
33 reserve base will always entail a careful consideration of possible alternatives that best
34 represents the idealized historic extent of the biotic reserve base.

35
36 The final results for biotic resource depletion are sensitive to the selection of the historic reserve
37 base which is used. Sensitivity analysis should be a key part of this selection process. A
38 description and justification of the historic reserve base selected must be provided in the LCA
39 report, along with a clear description of its extent and the data sources used in its classification.

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1 **2.4.4. Characterization**

2 **2.4.4.1. Potency Potential Characterization Factor.** In some cases, multiple biotic resources
3 exist which should be aggregated into a single category indicator. In these cases, PP-CFs must
4 be established which are used as the basis of equivalencies. The derivation of the PP-CF
5 depends upon the biotic resources in question.

6 **FOR EXAMPLE.** In a forest in the Southeastern United States, there are three tree species types which are
7 harvested for timber: longleaf and slash pines; loblolly and shortleaf pines; and other yellow pines. The PP-
8 CF accounts for any differences in material density or other characteristics which must be considered in
9 making equivalencies between these distinct timber types.

10 **2.4.4.2. Midpoint Characterization Factor.** The M-CF for this category indicator is the
11 Resource Depletion Factor (RDF), which is a factor which characterizes the drawdown of the
12 biotic reserve base compared to historic conditions. The RDF is calculated using Equation 2.6.
13 The RDF is unitless, but can be expressed as a percentage reduction in the extent of the historic
14 reserve base.

15
16 **Equation 2.6. Equation for calculating the Resource Depletion Factor for Biotic Resource Depletion.**

$$\text{RDF} = (\text{Historic Reserve Base} - \text{Current Reserve Base}) / \text{Historic Base}$$

Where:

- *RDF = Resource depletion factor*
- *Historic reserve base is the historic extent of the biotic reserve base, defined according to requirements in Section 2.4.3.*
- *Current reserve base is the current extent of the biotic reserve base.*

17 **2.4.4.2.1. Determining the Extent of the Biotic Reserve Base.** The stressor-effects network
18 linked to activities at a unit process in the anthropogenic system can vary greatly based upon
19 the region, past history of resource management, and other considerations (see Section 2.4.2).
20 The midpoint of the drawdown of the biotic reserve base (Node 3 in Error! Reference source
21 not found.) will also vary significantly. Accordingly, site-specific assessment of the extent of the
22 biotic reserve base is required.

23 The data sources and methods used to assess the extent of the biotic reserve base depends upon
24 the biotic resource which is depleted, region, species of biotic resource, and other considerations.
25 Monitoring data evaluating the extent of the biotic reserve base through direct measurement is
26 required.

27
28 For instances of biotic resource depletion which are associated with land-based unit processes
29 (i.e., forestry), the current biotic reserve base should be evaluated using data for a specific
30 classified area, which has experienced a drawdown in biotic resources as a result of current or
31 historic activities at the unit process under study.

32 **FOR EXAMPLE.** The biotic reserve base is assessed in 650,000 acres of forests in a county of the Pacific
33 Northwest of the United States. In these forests, the volume of sawlogs in sawtimber-grade trees is
34 approximately 2,000 cubic feet per acre. These forests are in private ownership, and have been affected by

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1 over 100 years of commercial forestry, involving heavy clear cutting. The reference reserve base is a forest
2 in an adjacent national park, with very similar species composition and ecological characteristics; here, the
3 volume of sawlogs in sawtimber-grade trees is approximately 13,000 cubic feet per acre. In the biotic
4 reserve base under study, this corresponds to a loss of roughly 11,000 cubic feet of sawlogs per acre, with
5 a corresponding RDF of 0.85.

6
7 If data is unavailable to assess the current or historic extent of the biotic reserve base, it may not
8 be possible to achieve the goals of the LCA study. The goal and scope may need to be revised.
9

10 **2.4.5. Indicator Equation and Unit of Measure.** Due to the diverse nature of the environmental
11 mechanisms for biotic resource depletion, different units of measure and indicator equations will
12 be applicable in different contexts. The indicator equation and unit of measure used should be
13 reported and described in the LCA report. PCRs shall specify the calculation methodology for this
14 indicator.

15 **2.4.6. Additional Reporting Requirements.** For a given unit process, the results for biotic
16 resource depletion can vary inversely with production levels in a nonlinear fashion. Increased
17 production, if that production is in excess of regrowth rates, leads to increasing indicator
18 results over time. Furthermore, due to the typically long recovery time required for biotic
19 reserve bases, even if all stressors associated with a given unit process were to stop, and all
20 production cease, in most situations, it would take decades for the biotic resource to recover to
21 its historic extent. As a result, indicator results normalized to production volumes (i.e.,
22 intermediate flows) can be misleading.

23 The functional unit should be scaled such that the total biotic reserve base which is affected by
24 unit process(es) in the anthropogenic system is included and reported in final results. Results
25 should not be normalized to production volume on the site. The RDF, expressed as a percentage,
26 and extent of the historic reserve base shall be reported in the LCIA profile.
27

28 **3. Global and Regional Climate System Impacts**
29

30 This impact group addresses three major impacts with distinct environmental mechanisms, which
31 are linked to emissions of CO₂ and other climate forcing substances (including precursors). This
32 includes emissions of greenhouse gases (GHGs), aerosols, particulates, and emission precursors.

33 NOTE. Some emissions addressed in these impact categories also have impacts on human health. This
34 includes emissions of black carbon, which is a component of particulate matter, and emissions of ozone
35 precursors, which can contribute to ground level ozone formation. Human health impacts linked to these
36 emissions are addressed in the impact categories of Ground Level Ozone Exposure Risks and PM2.5
37 Exposure Risks (see Sections 7.1 and 7.2 of the Annex).
38

39 The two impact categories considered in this group are: Global Climate Impacts and Regional
40 Climate “Hot Spot” Impacts.
41

- 42 • **Global Climate Impacts (Section 3.1).** This impact category addresses the wide range of
43 endpoints which are linked to global climate change. The PP-CF for this impact category is
44 calculated based upon the integrated climate (i.e., radiative) forcing of a given emission,
45 relative to the integrated climate forcing of an emission of CO₂, with units reported in mass

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1 of CO₂ equivalent (CO₂e). This is calculated using the Global Warming Potential (GWP)
2 equation for a pulse emission source, defined by the Intergovernmental Panel on Climate
3 Change (IPCC).⁶ The PP-CF, called the Integrated Global Climate Forcing Potential (I-GCFP),
4 or the Global Forcing Potential (GFP), is calculated using the GWP equation.

5 **Note.** This Standard uses the term, Integrated Global Climate Forcing Potential, rather than
6 the more common term, Global Warming Potential, to more accurately reflect the fact that the
7 factors characterize the global integrated radiative forcing of climate forcers relative to CO₂,
8 not any induced temperature change (which could be implied by the word “warming”).

9 **Note.** Additionally, the radiative forcing which is characterized in the I-GCFP may be
10 positive or negative (i.e., leading to warming or cooling). The term “Global Warming Potential”
11 implies that only positive forcing is considered.
12

13 To establish I-GCFPs, a time horizon must be selected to use in the GWP equation.⁷ In this
14 Standard, the time horizon used is based on the projected date of the exceedance of key global
15 mean temperature (GMT) anomaly thresholds. When these thresholds are exceeded, increasing
16 levels of anthropogenic interference with the climate system will occur.

17
18 Three key GMT anomaly thresholds are recognized in this Standard, based on the preponderance
19 of evidence:

- 20
21 • *+1.5C° GMT anomaly threshold, projected to be exceeded by approximately 2035.* The 52-
22 member Alliance of Small Island States (AOSIS) and the group of 49 Least Developed
23 Countries (LDC) are seeking a strict target to limit the GMT anomaly increase to +1.5°C.
24 This precautionary threshold was proposed in 2009 to serve as the agreed-upon
25 temperature target under the United Nations Framework Convention on Climate Change
26 process.
- 27 • *+2.0C° GMT anomaly threshold, projected to be exceeded by approximately 2050.* This
28 threshold was defined and agreed upon in the 2009 Copenhagen Accord under the UN
29 Framework Convention on Climate Change process as the threshold beyond which
30 “dangerous” impacts to the climate are likely to occur.⁸
- 31 • *+4.0C° GMT anomaly threshold, projected to be exceeded by approximately 2100.* The
32 preponderance of evidence suggests that beyond +4C°, the effects to the climate could be
33 “potentially devastating.”⁹
34

⁶ Intergovernmental Panel on Climate Change WGI: 2.10.1 Definition of an Emission Metric and the Global Warming Potential.

⁷ In this Standard, the GMT anomaly is the increase in global mean temperature compared to the pre-industrial era.

⁸ The 1992 UN Framework Convention on Climate Change has as its objective “to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.”

⁹ World Bank. *Turn Down the Heat: Why a 4°C Warmer World Must be Avoided*. 2013.

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1 Any one of these thresholds can be used as the basis of calculating results for Global Climate
2 Change using I-GCFPs; multiple results, linked to multiple time horizons, can also be used and
3 reported. The choice of threshold used in a given study depends on the goal and scope.

4 NOTE. These are “fixed-date” time horizons. This means that the time horizon used will decrease over
5 time as each impending threshold approaches.

6 NOTE. Although tied specifically to GMT anomaly thresholds, these time horizons can respectively be
7 considered to represent integrated climate forcing over the short-term, medium-term, and long-term.

8 NOTE. The GWP-100 was initially presented in 1990 along with GWP values calculated on
9 alternative time horizons (20 years and 500 years). When first published, it was noted that these three
10 time horizons (20 years, 100 years, and 500 years) were presented as “candidates for discussion [that]
11 should not be considered as having any special significance.”¹⁰ The IPCC, in its Fifth Assessment Report,
12 noted that “there is no scientific argument for selecting 100 years compared with other choices”.¹¹ This
13 Standard enables the use of different (or multiple) time horizons, recognizing that there is no clear single
14 choice of timeframe for considering the effects of emissions on climate forcing.

15
16 • **Regional Climate “Hot Spot” Impacts (Section 3.2).** The Standard recognizes regional “hot
17 spots” for climate change — i.e., areas affected by distinct regional environmental
18 mechanisms for climate change, that should be reported separately from the Global Climate
19 Change impact category. The Arctic is one such regional hot spot. The preponderance of the
20 evidence from studies conducted of this region show that the Arctic has experienced
21 accelerated warming compared to the planet as a whole. The Arctic Monitoring Assessment
22 Programme (AMAP) report, among others, provides data linking short-lived climate forcers,
23 such as black carbon, to as much as half of the Arctic radiative forcing anomaly. The method
24 for calculating the Arctic Climate Change profiles are based upon the Absolute Regional
25 Temperature Potentials developed by Dr. Drew Shindell and Dr. Gregory S. Faluvegi of the
26 National Aeronautics and Space Administration (NASA).¹²

27
28 As more is understood about distinct climatic environmental mechanisms in the Earth system,
29 additional regional impact categories may be considered (e.g., Antarctic Climate Change, Mid-
30 Latitude Band Climate Change, etc.).

31 **3.1. Global Climate Impacts**

32
33
34 **3.1.1. Impact Category.** The Global Climate Change impact category addresses the
35 contributions of “climate forcers,” including greenhouse gases (GHGs) and short-lived climate
36 forcers (SLCFs), to global climate change. Specifically, it characterizes the total radiative heat
37 trapped through radiative forcing before key thresholds in the Global Mean Temperature¹³

¹⁰ Houghton, J. T., G. J. Jenkins, and J. J. Ephraums, 1990: *Climate Change. The IPCC Scientific Assessment*. 364 pp.

¹¹ Intergovernmental Panel on Climate Change 2013. AR5. WGI, Section 8.7.1.2.

¹² Shindell, D.T. Evaluation of the absolute regional temperature potential. *Atmos. Chem. Phys.*, 12, 7955-7960, 2012.

¹³ GMT is typically measured on an annual average basis. Specifically, it is measured based on the area-weighted global average of the local departures of the daily-average of the observed maximum and minimum near-surface air temperatures at long-term stations.

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1 (GMT) anomaly are projected to be exceeded (as described in Section 3.1.1.1). In this Standard,
2 the GMT anomaly is the increase in global mean temperature compared to the pre-industrial
3 era.
4

5 A large number of endpoints are associated with this impact category, occurring on global,
6 continental, and regional scales, including: biome disturbance, especially to tundra, boreal
7 forest, mountain, Mediterranean-type ecosystems, coastal mangroves, and salt marshes; species
8 extinctions, especially in these biomes; severe impacts to tropical forests; contraction of
9 productive areas in polar sea-ice biomes; reduction in summer and autumn water flows due to
10 loss of water stored in glaciers and snow cover; melting of Himalayan-Tibetan glaciers that
11 provide water for more than one-sixth of the world population^{14, 15}; melting of terrestrial ice
12 sheets in Greenland, Antarctica, and other regions; melting of Himalayan glaciers and Arctic sea
13 ice (where black carbon has been shown to play a significant role)¹⁶; increases in drought-
14 affected areas; increases in occurrence of extreme precipitation events; enhanced sea-level rise
15 due to the melting of terrestrial ice sheets; increases in air pollution where pollution is already
16 significant^{17, 18}; warming of surface and deep ocean layers, leading to vertical stratification and
17 decreased nutrient cycling, coral bleaching, and other impacts; and a large number of other
18 endpoints affecting the environment and human health.¹⁹
19

20 **3.1.1.1. Definition of Exceedance of Threshold for Global Climate Change.** Three key GMT
21 anomaly thresholds exist, based on the preponderance of evidence. Corresponding to these
22 GMT thresholds, based upon the climate sensitivity values published by IPCC, are
23 corresponding radiative forcing (RF) thresholds. The date of each projected exceedance of
24 threshold is based on the preponderance of evidence from major climate models:^{20,21,22}
25

- 26 • +1.5C° GMT anomaly threshold, projected to be exceeded by approximately 2035, with
27 corresponding RF threshold of 2 W/m², which has already been passed.
- 28 • +2.0C° GMT anomaly threshold, projected to be exceeded by approximately 2050 with
29 corresponding RF threshold of 2.6 W/m², which will be passed between 2025 and 2035.
- 30 • +4.0C° GMT anomaly threshold, projected to be exceeded by approximately 2100, with
31 corresponding RF threshold of 5.2 W/m², which will be passed by roughly 2065.
32

¹⁴ W.W. Immerzeel, S. Kang, T. Gao, M. Menenti, P. Droogers, 2010. Hydrological and cryospheric modeling in the Qugaqie catchment on the Tibetan plateau: theoretical approach. Abstract for the Fourth International Workshop on Catchment-scale Hydrological Modeling and Data Assimilation (Lhasa, China, July 2010)

¹⁵ Kulkarni et al. *Glacial retreat in Himalaya using Indian Remote Sensing satellite data*. Current science 92 (1), 69-74.

¹⁶ Ramanathan, V., and G. Carmichael. *Global and regional climate changes due to black carbon*. Nature geoscience, 2008.

¹⁷ Jacobson, M.Z. On the causal link between carbon dioxide and air pollution mortality, *Geophysical Research Letters*, 35, L03809, doi:10.1029/2007GL031101, 2008

¹⁸ Jacobson, M.Z., The enhancement of local air pollution by urban CO₂ domes, *Environ. Sci. Technol.*, 44, 2497-2502, doi:10.1021/es903018m, 2010

¹⁹ Intergovernmental Panel on Climate Change. *Working Group II: Impacts, Adaptation, and Vulnerability. TS4.1 Sectoral impacts, adaptation, and vulnerability*. http://www.ipcc.ch/publications_and_data/ar4/wg2/en/tssts-4-1.html

²⁰ *Climate Change 2007*, IPCC 4th Assessment Report (AR4).

²¹ United Nations Environment Programme and World Meteorological Organization. *Integrated Assessment of Black Carbon and Tropospheric Ozone*. 2011.

²² Intergovernmental Panel on Climate Change. Fifth Assessment Report.

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1 The exceedance of each of these temperature thresholds will lead to increasing levels of
2 anthropogenic interference with the climate system, and each are relevant. Accounting for this
3 impact category shall consider RF changes until at least 2025 (until the 2.6 RF threshold is
4 passed), and shall not consider RF changes past 2065, based on the definition of the LCA time
5 horizon. The choice of LCA time horizon used in a given study depends on the goal and scope;
6 the goals and scope of the LCA study shall be stated clearly in this regard. The effect on final
7 results for Global Climate Change of the different LCA time horizons should be analyzed using
8 sensitivity analysis.

9
10 **3.1.2. Stressor Effects Network.** The stressor-effects network is global in scope, encompassing
11 the full spectrum of climate forcers contributing to global climate change, including but not
12 limited to: GHGs, absorbing and reflecting aerosols, and precursor emissions.

13
14 The stressor-effects network is shown in Table 3. 1 of Annex B.

15
16
17 **3.1.2.1. Selection of Category Indicator.** The indicator for this impact category shall be at
18 Node 3, the characterization of the radiative forcing (in mW / m²) each year.

19
20 Only one environmental mechanism is relevant for this impact category: Global Climate Change.
21 Accordingly, only one category indicator is reported.

22
23 **3.1.2.2. Identifying Core Impact Categories and Category Indicators.** All known
24 anthropogenic systems have stressors associated with this impact category. Global Climate
25 Change is a core impact category for all LCA studies.

26
27 In cases where the net result for Global Climate Change is negligible, results shall still be reported,
28 noting in the LCIA profile that stressors are contributing to both positive and negative radiative
29 forcing, but that net results are negligible.

30
31 **3.1.3. Classification.** This impact category includes all emissions and activities which can be
32 linked to positive or negative climate forcing (i.e., both warming and cooling are considered).

33
34 For certain unit processes, there may be activities linked to climate forcing effects, which are not
35 associated with emissions. This can include effects from land use change, surface albedo changes,
36 carbon uptake/storage, or the long-term loss of carbon storage in biogenic systems. These
37 additional climate forcing effects shall be included, if they are relevant to final indicator results,
38 depending on the goal and scope of the study.

39
40 **3.1.3.1. Classifying Emissions Contributing to Radiative Forcing.** Emissions that lead to
41 measurable radiative forcing are classified in this impact category. This shall include all
42 emissions or other activities that cause direct radiative forcing, as well as those that lead to
43 radiative forcing indirectly, through effects such as chemical reactions in the atmosphere and
44 effects on cloud cover.

45
46 This includes substances with broadly varying atmospheric lifetimes. The atmospheric lifetime
47 affects both the timeframe of response to emissions mitigation, and whether the forcing which is

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1 caused occurs regionally or globally. Three categories of substances with climate forcing
2 properties are defined:
3

- 4 • Long-lived greenhouse gases (LLGHGs) Emissions causing force which have an average
5 atmospheric lifetime of over 100 years.
- 6 • Mid-Lived climate forcers (MLCFs) or Mid-lived climate pollutants (MLCPs) emissions
7 causing forcing which has an average atmospheric lifetime longer than the inter-
8 hemispheric mixing time of the Earth's atmosphere (12 to 18 months), but less than 100
9 years.
- 10 • Short-Lived Climate Forcers (SLCFs) or Short-Lived Climate Pollutants (SLCPs) emissions
11 causing force which have an average atmospheric lifetime which is shorter than the mixing
12 time between the northern and southern hemispheres of the Earth's atmosphere (12 to 18
13 months), causing uneven hemispheric (i.e., regional) and global forcing.
14

15 The emissions to be classified include, but are not limited to: all of the GHGs included in the Kyoto
16 Protocol and commonly included in GHG accounting frameworks; all relevant short-lived climate
17 forcers (SLCFs); all Ozone Depleting Substances (ODSs) included in the 1987 Montreal Protocol,
18 which cause direct warming, and indirect cooling through depletion of stratospheric ozone²³; and
19 aerosols and their precursors leading to negative radiative forcing (sulfates and nitrates). A list
20 of substances to be classified is included in Table 3.2. Note that this list is not comprehensive, and
21 there may be other emissions occurring at unit processes in the anthropogenic system under
22 study should be classified.
23

²³ Ramanathan,V., L. B. Callis and R. E. Boughner, 1976: Sensitivity of Surface Temperature and Atmospheric Temperature to Perturbations in Stratospheric Concentration of Ozone and Nitrogen Dioxide. J. Atmos. Sci., 33: 1092-1112.

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1
2

Table 3.2. Emissions of climate forcers to be classified.

Well Mixed GHGs	Very Short-Lived Climate Forcers
Carbon dioxide (CO ₂)	Black carbon aerosol
Carbon tetrachloride*	Brown carbon aerosol
Chlorofluorocarbons (CFCs)*	Carbon monoxide
Halons*	Mineral dust aerosol ²⁴
Hydrochlorofluorocarbons (HCFCs)**	Nitrogen oxides
Methyl Bromide*	Organic carbon aerosols (other than Brown Carbon)
Nitrous oxide (N ₂ O)	Other ozone precursors
Perfluorocarbons	Sea salt aerosols
Sulfur hexafluoride (SF ₆)	Sulfur dioxide**
Short-Lived Climate Forcers	VOCs
Methane	
Hydrofluorocarbons (HFCs)	

3 * These ozone-depleting substances lead to an indirect cooling effect through the destruction of stratospheric ozone. This
4 indirect cooling effect shall be included, even though for these pollutants, the net effect on a global-mean basis may be
5 positive radiative forcing due to their stronger direct positive radiative effects.

6 ** A fraction of sulfur dioxide (SO₂) emissions convert into tropospheric sulfate aerosols (TSA), which cause significant
7 direct negative radiative forcing by increasing the clear-sky albedo when the air is over a dark surface. The indirect effects
8 of this aerosol can cause additional negative radiative forcing through effects on clouds, including changes in cloud
9 lifetime, brightness, and amount. While a fraction of SO₂ emissions can be converted into particulate matter that can cause
10 significant human health effects, these health effects are addressed in the PM_{2.5} impact category (see Annex A, Section
11 6.2).
12

13 **3.1.3.2. Classification of Effects on Biogenic Systems.** In some anthropogenic systems,
14 certain unit operations cause significant effects to biogenic systems which are linked to effects
15 on radiative forcing. These are typically unit operations that have associated biogenic
16 absorption of atmospheric CO₂ (i.e., CO₂ absorption from photosynthesis), or which disrupt
17 existing carbon storage pools through harvests or other changes, causing releases. This leads to
18 inputs and outputs (i.e., absorption and emissions) of CO₂ and other substances, such as
19 methane. These inputs and outputs are classified.
20

21 For such unit operations, the absorption and emissions of CO₂ and other substances shall be
22 attributed solely to the unit operation in which they occur. If an intermediate flow of “biogenic”
23 carbon is emitted during combustion or decay associated with a different unit process elsewhere
24 in the anthropogenic system, resulting emissions of CO₂ and other substances must be attributed
25 to the unit process in which emissions occur, accounting for the time of emission. In this way,
26 actual flows of biogenic carbon, which typically enter the anthropogenic system via absorption
27 of atmospheric CO₂ and leave the system through decay or combustion processes, must be traced

²⁴ Mineral dust may cause warming or cooling, depending on the iron and aluminum content and the particle size. See Jacobson, M.Z., Global direct radiative forcing due to multicomponent anthropogenic and natural aerosols, *J. Geophys. Res.*, 106, 1551-1568, 2001.

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1 across the anthropogenic system. This more accurate accounting of carbon flows avoids
2 simplistic assumptions such as counting CO₂ emitted at a tailpipe which was initially stored via a
3 biogenic process as “carbon neutral.”²⁵
4

5 For some unit operations, practices have led to a change in biogenic carbon storage levels in the
6 regional biome, when compared to an undisturbed condition unaffected by anthropogenic
7 activities. In these cases, biome disturbance which can be linked to unit process(es) in the
8 anthropogenic system under study has led to a net change in the atmospheric burden of climate
9 forcers. This net change in atmospheric burden of climate forcers shall be classified and the RF
10 resulting from foregone growth in the biome shall be considered over the LCA time horizon.
11

12 NOTE. In practice, effects on biogenic systems are considered only if impact categories in the group of Land
13 Use Ecological Impacts are relevant, according to the requirements of Section 3 of the Annex.
14

15 The radiative forcing resulting from this additional atmospheric burden of climate forcers is then
16 assessed over time using Climate Forcing Profiles (see Section 3.1.4.1.2).
17

18 **FOR EXAMPLE.** For lumber products, timber harvests usually lead to significant reductions in the
19 amount of carbon stored in regional forests, when compared to undisturbed conditions. While some of the
20 carbon which was removed in timber may be stored in durable products, in most cases, the majority will
21 have decayed or combusted, resulting in emissions of CO₂ and CH₄ to the atmosphere. The net increased
22 atmospheric burdens of CO₂ and CH₄ shall be classified.
23

24 When assessing inputs and outputs for a unit operation affecting a biogenic system, site-specific
25 measurements will be required to track both fluxes and long-term carbon storage loss. If this type
26 of data is unavailable, the relevance to final study results from omitting these flows should be
27 considered. A confidence interval can be reported. Results may have to be reported using an
28 earlier node (see Section 3.1.2.1). If an omission has strong significance to final results, the goal
29 and scope of the study may need to be revised.
30

31 **3.1.4. Characterization.**
32

33 Characterization is based on calculation of radiative forcing each year, which is calculated
34 according to the following requirements. Requirements for characterizing RF can be found in
35 Annex C.
36
37

²⁵ Searchinger, T.D., S. P. Hamburg, J. Melillo, W. Chameides, P. Havlik, D. M. Kammen, G. E. likens, R. N. Lubowski, M. Obersteiner, M. Oppenhemier, G. P. Robertson, W. H. Shclesinger, and G. D. Tilman. Fixing a Critical Climate Accounting Error. Policy Forum. Science: Vol. 326, 527-528. October 2009.

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1 **3.1.5. Indicator Equation and Unit of Measure.** The indicator result at Node 3 for unit
2 processes is calculated using Equation 3.3. Results are calculated in mW m⁻².
3

4 **Equation 3.3.** The equation to be used to calculate radiative forcing occurring ‘n’ years after the beginning of the time
5 horizon, in units of milliwatts per square meter (mW/m²), from emissions (RF emissions) and other effects.

$$RF\ total\ (n) = RF\ emissions(n) + RF\ other\ effects\ (n)$$

Where:

- *RF Emissions* represents the RF resulting from all emissions linked to the anthropogenic system
- *RF Emissions* represents the RF resulting from all other activities and processes linked to the anthropogenic system

6
7 **3.1.6. Additional Reporting Requirements.** The contribution to positive and negative
8 radiative forcing (warming and cooling) shall be reported separately, without being combined
9 as a net value.
10

11 **3.1.7. Addressing Limitations in Types, Accuracy, and Availability of Environmental Data.**
12 In some cases, there is insufficient data to characterize RF. In these cases, conservative
13 assumptions should be made regarding the RF. In this case, the description of the assumptions
14 and methods used shall be included in the LCA report.
15

16 In some cases, even a defensible upper or lower confidence bound of indicator results cannot be
17 assessed with the available data. In these cases, results must be reported as inventory flows. This
18 will limit the environmental relevance of results; this must be disclosed in the LCA report. For
19 EPDs, the resulting limitations in comparability must also be described.
20

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1
2 **3.2. Regional Climate “Hot Spot” Impacts**
3

4 These impact categories address the impacts from emissions of certain SLCPs on the following “hot
5 spots” identified by UNEP²⁶:

- 6 • Arctic
- 7 • East Asia.
- 8 • South Asia.
- 9 • Southeast Asia.
- 10 • Indonesia/Malaysia.
- 11 • South America.
- 12 • Central Africa.

13 These impacts are relevant only if operations product are located in these regions, and emit black
14 carbon, nitrogen oxides, sulfur dioxide, carbon monoxide, volatile organic compounds (VOCs), or
15 other pollutants contributing to these local climate hot spots. These pollutants shall be
16 considered as a default.

17 The result for a single climate hot spots, in $mW m^{-2}$, is calculated according to the equation below,
18 for a given year in the timeframe of analysis. RF shall be characterized following all requirements
19 of Annex C.

20 **Equation 1. Result for climate hot spots.**

Climate Hot Spot Impacts ($mW m^{-2}$) in a given year =

$$\sum_i \sum_j \text{Short-Lived Climate Pollutant Emissions}_{i,j} \times RRE_j$$

Where:

- *Short-Lived Climate Pollutant Emissions are tons resulting for the annual unit of analysis in the year, including the following pollutants: black carbon, nitrogen oxides, sulfur dioxide, carbon monoxide, VOCs, or other pollutants contributing to the local climate hot spot.*
- *i is the total number of unit processes in the scope*
- *j represents the total number of SLCPs emitted*
- *RRE_j is the regional radiative efficiency of the jth SLCP, which is the regional RF induced in the climate hot spot per million tons of emissions, in units of $mW m^{-2} Tg^{-1}$.*

²⁶ Ramanathan, V., et al., (2008), Atmospheric Brown Clouds: Regional Assessment Report with Focus on Asia. Published by the United Nations Environment Programme, Nairobi, Kenya.

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1
2
3
4 **4. Ocean Ecosystems Impacts**

- 5
6 • **Ocean Acidification (Section 4.1).** This impact category represents the distinct
7 environmental mechanism linked to the increase in carbonic acid concentrations and
8 subsequent drop in ocean pH in the world's oceans caused by oceanic absorption of CO₂.
9 These midpoints and endpoints are unique from climate change and have nothing to do with
10 radiative forcing. The environmental mechanism includes effects on Aragonite saturation
11 levels, and subsequent effects on marine organisms of many types around the world.

12
13 **4.1. Ocean Acidification**

14
15 **4.1.1. Impact Category.** This impact category represents the degree to which CO₂ emissions
16 lead to decreases in the pH of the ocean through the formation of carbonic acid, negatively
17 impacting coral reefs and other marine life by lowering both the aragonite and calcite
18 saturation levels.

19
20 Ocean acidification represents an increasing risk of disruption of the global ocean ecosystem.
21 Acting along with other ocean stressors, including ocean warming, increases in eutrophication
22 on a large scale, trash, chemical releases such as mercury, overfishing, and other stressors, ocean
23 acidification is contributing to increasing risk to the ocean biosphere.

24
25 **4.1.2. Stressor-Effects Network.** The stressor-effects network relates to the net absorption of
26 atmospheric CO₂ into the world's oceans as carbonic acid (H₂CO₃), and is shown in Table 4.1 of
27 **Annex B.**

28
29
30 **4.1.2.1. Selection of the Category Indicator.** Proceeding along the environmental mechanism,
31 the environmental relevance of the possible category indicators for ocean acidification is low
32 until Node 4, representing the decrease in ocean pH. Nodes 1-3 are poorly reflective of
33 endpoints as they characterize neither changes in ocean pH, nor the measurement of reductions
34 in Aragonite saturation state, which directly impacts marine calcifying organisms. The node of
35 decreased ocean pH is considered to moderately reflect endpoints, as it is closely linked to the
36 reduction in aragonite saturation, which varies with ocean pH along with other aspects of ocean
37 chemistry and temperature.

38
39 The reduction in Aragonite saturation state strongly reflects the endpoints of impacts on marine
40 organisms, particularly calcifiers, and so has high environmental relevance. However, there are
41 no recognized characterization models with which to establish characterization factors at this
42 node. By contrast, a characterization model for the indicator at Node 4, based on increases in
43 carbonic acid concentrations, is well defined, and the data required to characterize it are readily
44 available.

45
46 The indicator result shall be characterized at Node 4, the oceanic absorption of carbonic acid.
47

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1 Only one environmental mechanism is relevant for this impact category: Ocean Acidification.
2 Accordingly, only one category indicator is reported.
3

4 **4.1.2.2. Identifying Core Impact Categories and Category Indicators.** All known
5 anthropogenic systems emit carbon dioxide; for all LCA studies, Ocean Acidification will be a
6 core impact category.
7

8 **4.1.3. Classification.** CO₂ and other carbon-containing chemicals (e.g., methane) that are
9 ultimately oxidized into CO₂ in the atmosphere are the only chemicals that contribute to this
10 indicator. All CO₂ emissions are included in this impact category, as well as emissions of
11 methane and other substances that are chemically converted in the atmosphere into CO₂. Other
12 emissions can be classified if they have a relevant effect on ocean acidity.
13

14 **4.1.3.1. Classification of Effects on Biogenic Systems.** The classification of effects from
15 biogenic systems for this impact category shall include all of the same flow(s) classified for
16 Global Climate Change. The same guidance and provisions apply (see Section 3.1.3.2).
17
18

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1 **4.1.4. Characterization**

2
3 **4.1.4.1. Potency Potential Characterization Factors (PP-CFs).** The PP-CF characterizes the
4 conversion rate of atmospheric CO₂ into carbonic acid in the oceans, on a mass basis. One mole
5 of CO₂ dissolved in the ocean converts into one mole of carbonic acid. Other substance
6 emissions that convert into CO₂ in the atmosphere include methane; it should be assumed that,
7 over time, these other emissions will be fully converted to CO₂. The PP-CF for these other
8 emissions accounts for their relative molar mass compared to CO₂. The PP-CFs for CO₂ and
9 methane, the two primary contributors to this indicator, are shown in Table 4.2, in units of
10 kilogram carbonic acid per kilogram of emission.

11
12 **Table 4.2. PP-CFs Used for Ocean Acidification**

13

Substance	Potency Potential Characterization Factor (kg H ₂ CO ₃ / kg)
Carbon Dioxide	1.41
Methane	3.87

14
15
16 **4.1.4.2. Midpoint Characterization Factor.** The M-CF accounts for the net fraction of CO₂
17 emissions associated with a unit process that is absorbed by the ocean within the study time
18 horizon. Approximately 25% of each year's CO₂ emissions is absorbed by the oceans.^{27, 28}
19 Accordingly, when considering CO₂ emissions over short timeframes, the CO₂ Absorption Factor
20 for most unit operations is 0.25. The absorption rate of 25% is measured on an annual basis,
21 and is representative of the fraction of present-day emissions of CO₂ that will be absorbed by
22 the oceans on the timescales relevant to most LCA studies.

23
24 Over longer time scales, as carbon is transported to the deep ocean layers and sediments through
25 mixing, overturning, and biological and chemical removal, the ocean will absorb a significantly
26 larger fraction of the emitted CO₂ than 25%. Since the Industrial Revolution, the equivalent of
27 approximately one-third of CO₂ emissions have been absorbed by the oceans.²⁹ If the scope of the
28 LCA study considers emissions over long time scales, the CO₂ Absorption Factor will need to
29 account for the increased absorption that occurs over longer time periods.

30
31
32 **4.1.4.3. Characterization of Changes in Biogenic Carbon Storage Levels.** When relevant, the
33 increased burden of H₂CO₃ in the oceans associated with the net change in the atmospheric
34 burden of CO₂ resulting from the changes in biogenic carbon storage levels shall be
35 characterized.

36
37 **4.1.5. Indicator Equation and Unit of Measure.** The indicator result at node 4 is calculated
38 using Equation 4.1. It is reported in mass of carbonic acid (H₂CO₃). The indicator is called the

²⁷ Global Carbon Project. *Global Carbon Budget*. <http://www.globalcarbonproject.org/carbonbudget/12/data.htm>

²⁸ National Oceanic and Atmospheric Administration: PMEL Carbon Program. *Ocean Acidification: The Other Carbon Dioxide Problem*. <http://www.pmel.noaa.gov/co2/story/Ocean+Acidification>

²⁹ Sabine, C. L., et al. *The Oceanic Sink for Anthropogenic CO₂*. *Science* 305, 367 (2004).

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1 carbonic acid formation. As this is an accumulated midpoint, the indicator result is calculated as
2 an accumulation over the total number of years in the LCA time horizon.

3 **Equation 4.1. Indicator result for Ocean Acidification for a single unit process, calculated at**
4 **node 4 (carbonic acid formation).**

$$\text{Carbonic Acid Formation} = \sum_j \sum_i (\text{Emissions in year } j \times \text{PP-CF}_i \times \text{M-CF})$$

Where:

- *PP-CF_i* represents the kilograms of carbonic acid produced per kilogram of substance *i* emission
- *M-CF* represents the CO₂ absorption fraction
- *j* represents the total number of years in the LCA time horizon (for this accumulated midpoint)
- *i* represents the total substances contributing to ocean acidification emitted from a unit process

5
6 **4.1.6. Reporting Requirements.** There are no special reporting requirements for category
7 indicator results for Ocean Acidification.

8
9
10 **4.2. Ocean Warming**

11
12 Of the total excess heat trapped by climate pollutants since 1750, over 90% has been absorbed
13 by the oceans. This has led to major impacts such as changes in populations of species in different
14 regions, decreases in vertical mixing, and other effects.

15
16 Ocean warming is linked to global climate change effects, but the scale and timeframe of impacts
17 justifies its treatment as a separate impact category. However, at this time, there is no metric
18 available to assess the effect of climate pollutants on ocean warming. This impact category shall
19 be listed in final results, and results can be listed as “No data”.

20
21 If an LCA study is developed providing results for this impact category, the methodology and data
22 sources used to generate results shall be transparently reported in the LCA report, and should be
23 subject to peer review. PCRs should be developed for situations where this impact category is
24 relevant, in order to provide metrics for calculation of results.

25
26 **4.2. Ocean Warming Hot Spots**

27
28 Some regions of the world’s oceans have experienced significantly higher warming than the
29 global average. In identifying ocean warming hot spots, the specific oceanic region of the
30 affected hot spot shall be specified. Ocean hot spots are regions experiencing:

- 31 • Sea surface and/or water column temperatures elevated significantly above the global
32 mean average;
- 33 • Periodic episodes of very high oceanic temperatures;
- 34 • Have experienced significant ecosystem disruptions as a result of elevated ocean
35 temperatures;
- 36 • Significant coral bleaching events (if corals exists in the region);

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- 1 • Other considerations.

2 Ocean warming hot spots may be episodic, periodic, or perennial in nature. In identifying ocean
3 hot spots, the spatial extent of the hot spot should be understood, and nature of local alterations.

4
5 The following are existing ocean warming hot spots observed in 2016. Additional hot spots can
6 be identified provided the requirements of this section are met.

- 7 • Northeastern Pacific region (off the western coast of North America);
8 • Equatorial Eastern Pacific;
9 • Equatorial Western Pacific;
10 • Indian Ocean;
11 • Australian Great Barrier Reef.

12 NOTE. Sources used to identify these hot spots include AMS State of the Climate 2014 Report Chapter 3,³⁰
13 and NOAA Coral Reef Watch.³¹

14
15 Ocean hot spots are linked to global ocean warming effects, but the scale and timeframe of
16 impacts justifies its treatment as a separate impact category. However, at this time, there is no
17 metric available to assess the effect of climate pollutants on ocean warming. This impact category
18 shall be listed in final results, and results can be listed as “No data”.

19
20 If an LCA study is developed providing results for this impact category, the methodology and data
21 sources used to generate results shall be transparently reported in the LCA report, and should be
22 subject to peer review. PCRs should be developed for situations where this impact category is
23 relevant, in order to provide metrics for calculation of results.

24
25
26 **4.3. Marine Biome Disturbance**

27
28 This impact category is linked to disturbances to marine biomes such as coral reefs, being caused
29 by a number of different impact vectors. The specifics set of stressors, midpoints, and endpoints,
30 will depend upon the industry sector and affected marine biome. This Standard does not specify
31 requirements for accounting. If relevant, this impact category shall be listed in final results, and
32 results can be listed as “No data”.

33
34 If an LCA study is developed providing results for this impact category, the methodology and data
35 sources used to generate results shall be transparently reported in the LCA report, and should be
36 subject to peer review. PCRs should be developed for situations where this impact category is
37 relevant, in order to provide metrics for calculation of results.

³⁰ <https://www.ametsoc.org/ams/index.cfm/publications/bulletin-of-the-american-meteorological-society-bams/state-of-the-climate/chapter-3-global-oceans/>

³¹ <http://coralreefwatch.noaa.gov/satellite/hotspot.php>

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1 **4.4. Marine Eutrophication**

2 **4.4.1. Impact Category.** This impact category addresses marine eutrophication impacts,
3 including eutrophication in estuaries, bays, or other marine ecosystems. Marine eutrophication
4 usually occurs when nutrients (biologically available nitrogen and phosphorus) are added
5 beyond a receiving water body’s ability to process them. This leads to increases in primary
6 productivity of algae, which in turn leads to multiple and complex changes to aquatic ecosystems,
7 including blooms of microscopic and macroscopic algae, and increased turbidity in the water
8 column. Marine eutrophication typically occurs as a result of indirect runoff from emissions to
9 soil. These effects are often called the “primary symptoms” of eutrophication, and are herein
10 referred as such.

11
12 Increased decay as a result of increased algae formation will eventually deplete levels of
13 dissolved oxygen, leading to hypoxia and anoxia; this depletion in oxygen levels leads to major
14 disruptions to local ecosystems as organisms that require oxygen cannot survive. These effects
15 are sometimes called the “secondary symptoms” of eutrophication, and are herein referred as
16 such.

17
18 **4.4.1.1. Definition of Threshold Exceedance for Eutrophication.** A receiving water body
19 may be in exceedance of threshold for primary and/or secondary symptoms. Threshold
20 exceedance is determined separately for each type of symptom.

21
22 Receiving water bodies in exceedance of threshold for primary symptoms are those in which
23 algae concentrations are above levels that the receiving water body can accept. These water
24 bodies are experiencing negative effects to local ecosystems from primary symptoms, including
25 reduction in benthic vegetation, and increased turbidity.

26
27 For a specific receiving water body, the conditions used to define the threshold for primary
28 symptoms of eutrophication shall be quantitatively based, usually based upon measures of
29 primary productivity in the water column, including but not limited to: mean productivity,
30 chlorophyll-a concentrations, or algal biomass. Exceedance can also be based on concentrations
31 of total phosphorus or nitrogen. The specific conditions of these measurements must be defined
32 depending upon the characteristics of the affected receiving water body, considering the marine
33 setting in which it is present. The definition of the specific measures used to determine if a region
34 is in exceedance of threshold for primary symptoms can be based upon local regulations.

35
36 For secondary symptoms of eutrophication, regions in exceedance of threshold include those in
37 which the level of dissolved oxygen in the water column is below certain thresholds for hypoxia.
38 Aerobic organisms in water bodies experiencing this exceedance are already seriously impacted.

39
40 For a specific receiving water body, the conditions used to define the threshold for secondary
41 symptoms shall be based on measures of dissolved oxygen. The specific threshold values can vary
42 based on local characteristics of the receiving water body; the exceedance of threshold values in
43 Table 5. 5 can be used as a reference. Most regulatory frameworks, including the US
44 Environmental Protection Agency, recognize 5 mg/L of dissolved oxygen content as a threshold
45 for eutrophication.

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**Table 5. 1. Threshold characterization and exceedance of threshold values,
based upon the concentration of dissolved oxygen**

*Source: National Oceanic and Atmospheric Administration,
Effects of Nutrient Enrichment on the Nation's Estuaries. 2007.*

State	Dissolved Oxygen Content, mg/L	Threshold Condition
Anoxia	0	Exceedance of Threshold
Hypoxia	0-2	Exceedance of Threshold
Biological Stress	2-5	Exceedance of Threshold
	>5	Above Threshold

When determining the exceedance of threshold for primary or secondary symptoms in a specific water body, the temporal nature of eutrophication should be considered. Depending upon local conditions, exceedance of threshold could be episodic (i.e., occurring at infrequent intervals), periodic (i.e., occurring at frequent and predictable intervals, usually during the growing season), or persistent (i.e., occurring on a continuous basis). Understanding the temporal nature of the midpoint of exceedance of threshold can aid in characterization. The basis of determination of whether a receiving water body is in exceedance of threshold for either primary or secondary symptoms of eutrophication shall be described and justified in the LCA report.

4.4.2. Stressor-Effects Network. The stressor-effects network for this impact category depends upon the size, nature, location, timing, and duration, of an emission, as well as other considerations. The resulting scale, severity, timing, and duration of midpoints in the stressor effects network will vary for many reasons.

The stressor effects network for this impact category, shown in **Error! Reference source not found.**2 of Annex B, provides a general framework; however, for each receiving water body experiencing eutrophication which is affected by eutrophying emissions within the study scope (based upon the requirements of Section 5.4.2.1 and 5.4.2.2), a separate stressor-effects network should be modeled, describing the site-specific circumstances of stressors, midpoints, and endpoints, in the cause-effect relationship. This will greatly aid in the characterization of results, and will ensure that only relevant impacts are included.

Table 5. 2. Stressor effects network for Eutrophication.

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Node	Characterization of the Node	Uncertainty Arising from Weakness in Linkage to Endpoints	Uncertainty in Characterization, and Data Required to Characterize this Node
1 (Stressors) <i>High overall uncertainty. (Low environmental relevance.)</i>	Emissions of eutrophying substances associated with activities at a unit process.	<i>High uncertainty.</i> Characterization does not consider: the transport of eutrophying emissions in the receiving environment; subsequent increase in algae concentrations; subsequent decrease in depletion of oxygen concentrations; or endpoints resulting from primary and/or secondary symptoms of eutrophication.	<i>Low uncertainty.</i> Data requirements: Emissions levels of eutrophying substances. Potential for increased algae formation from emissions.
2 (Midpoint) <i>High overall uncertainty. (Low environmental relevance.)</i>	Contribution to increases in nutrient and algae concentrations in the receiving environment as eutrophying emissions from a unit process transport in the receiving environment.	<i>High uncertainty.</i> Characterization does not consider: increase in algae concentrations in regions in exceedance of threshold; subsequent decrease in depletion of oxygen concentrations; or endpoints resulting from primary and/or secondary symptoms of eutrophication.	<i>Low uncertainty.</i> Data requirements: Emissions levels of eutrophying substances. Potential for increased algae formation from emissions. Transport modeling data for eutrophying substances.
3 (Midpoint) <i>Moderate overall uncertainty. (Moderate environmental relevance.)</i>	Contribution to primary symptoms of eutrophication, when a fraction of eutrophying emissions transport to regions in exceedance of threshold for primary symptoms of eutrophication. These symptoms occur in an episodic, periodic, or persistent basis.	<i>Moderate uncertainty.</i> This indicator has moderate linkage to endpoints, as it takes into account the transport of emissions into regions in exceedance of threshold for the primary symptoms of eutrophication.	<i>Moderate uncertainty.</i> Data requirements: Emissions levels of eutrophying substances. Potential for increased algae formation from emissions. Transport modeling data for eutrophying substances. Data on conditions in the receiving environment regarding primary symptoms of eutrophication (i.e., chlorophyll concentrations, total P, or total N).

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<p>4 (Midpoint)</p> <p><i>Moderate overall uncertainty. (Moderate environmental relevance.)</i></p>	<p>Contribution to secondary symptoms of eutrophication, as increased algae growth occurs in regions in exceedance of threshold for secondary symptoms of eutrophication. Increased algae growth leads to increased decay of organic matter, and subsequent depletion of dissolved oxygen. These symptoms occur in an episodic, periodic, or persistent basis.</p>	<p><i>Low uncertainty.</i></p> <p>This indicator has linkage to endpoints, as it takes into account the transport of emissions into regions in exceedance of threshold for the secondary symptoms of eutrophication, which are typically the most significantly impacted regions.</p>	<p><i>Moderate uncertainty.</i></p> <p>Data requirements: Emissions levels of eutrophying substances. Potential for increased algae formation from emissions. Transport modeling data for eutrophying substances. Data on conditions in the receiving environment regarding secondary symptoms of eutrophication (i.e., dissolved oxygen concentrations).</p>
<p>5 (Endpoint)</p> <p><i>Characterization at this node not possible given data limitations.</i></p>	<p>Endpoints occur as a result of both primary and secondary symptoms, including effects to aerobic organisms such as fish, elimination of aquatic bottom vegetation, harmful and toxic algal blooms, and further ecosystem disruptions</p>	<p><i>Low uncertainty.</i></p> <p>Directly reflective of endpoints.</p>	<p>Data is not available to characterize contribution of an emission to endpoint of eutrophication.</p>

1
2 The stressor effects network in **Error! Reference source not found.**2 of Annex B includes both
3 primary and secondary symptoms of eutrophication. However, in some cases, primary symptoms
4 can occur and lead to endpoints, without the occurrence of secondary symptoms. In these cases,
5 this stressor effects network will not apply, as the midpoint at Node 4 does not occur, and
6 endpoints will be distinct. This illustrates the need to develop the stressor effects network for
7 eutrophication separately each affected receiving water body included in the study scope.
8
9

10 **4.4.2.1. Selection of Category Indicator(s).** For each receiving water body affected by
11 emissions of eutrophying substances which can be linked to unit process(es) in the
12 anthropogenic system under study, a distinct category indicator should be reported, provided a
13 distinct characterization model is established. A description and justification for the category
14 indicators which are reported shall be provided in the LCA report.

15 NOTE. This disaggregation is based upon the distinct nature of the stressor effects network of
16 eutrophication in distinct water bodies.
17

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1 The characterization model which is used depends on the state of threshold exceedance in the
2 affected receiving water body. If the receiving water is in exceedance of threshold for secondary
3 symptoms, characterization shall be at Node 4, characterizing the fraction of an emission
4 transporting to areas in exceedance of threshold. If the receiving water is in exceedance of
5 threshold only for primary symptoms, characterization shall be at Node 3.

6
7 In some cases, characterization may be not be possible at these nodes, as a result of lack of
8 environmental data, or lack of data regarding the locations of unit process(es) in the
9 anthropogenic system. In these cases, characterization can be at Node 1, representing emissions
10 levels of eutrophying substances, provided that Eutrophication is determined to be a core impact
11 category according to the requirements of Section 5.4.2.2.

12
13 Characterization at Node 1 has low environmental relevance. This level of environmental
14 relevance shall be described in the LCA report and wherever results are reported.

15
16 In rare cases, emissions of both nutrients and organic chemicals directly contributing to oxygen
17 depletion may be affecting the same receiving water body in exceedance of threshold for
18 secondary eutrophication. In these cases, equivalencies can be established to aggregate nutrients
19 and oxygen depleting chemicals into a single category indicator, using PP-CFs. The basis of such
20 equivalencies must be described in the LCA report. If no equivalencies can be established using
21 credible research, then aggregation is not possible.

22
23 **4.4.2.2. Identifying Core Impact Categories and Category Indicator(s).** Due to the extensive
24 data collection and analysis required to characterize category indicators for this impact category,
25 it is essential to carefully screen the anthropogenic system under study to identify unit
26 process(es) which are contributing to eutrophication in receiving water bodies which are in
27 exceedance of threshold (Node 3 or 4 in the stressor-effects network). This screening should be
28 intended to minimize the amount of data collection required, by focusing the scope of the study
29 on emission(s) associated with a anthropogenic system which are linked to eutrophication in
30 regions in exceedance of threshold.

31
32 For a specific unit process, eutrophication should be included as a relevant core impact category,
33 if the following conditions are satisfied:

- 34
- Eutrophying emissions can be linked to activities at the unit process.
 - The eutrophying substances resulting from these emissions transport to a receiving water
35 body in exceedance of threshold for eutrophication (either primary or secondary
36 symptoms).
- 37

38 In the first iteration, the potential for eutrophication should be assessed at Node 1, using PP-CFs.
39 The unit process(es) which are the main contributors to the potential for eutrophication should
40 be identified, and their region determined. The nature of these unit process(es) should be
41 considered, to understand similar unit processes that have been known in the other cases to have
42 emissions which contribute measurably to eutrophication in local receiving water bodies. For
43 these unit process(es), the local regulatory setting and regional conditions should be understood.

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1 The most significant type of unit process contributing to eutrophication is agriculture, especially
2 in certain regions, such as the Midwestern region of the United States. If agriculture in such a
3 region is found to be a significant contributor to final results for the potential for eutrophication,
4 then the specific emissions linked to activities at this unit process should be understood, and the
5 contribution to eutrophication in regions of exceedance of threshold determined.

6
7 Care should be taken when interpreting the outputs of LCI models, when using secondary
8 inventory databases. Emissions of eutrophying substances can vary broadly based upon the type
9 of unit process, regional practices, emission types, season of emission, and other considerations;
10 this means that secondary inventory data may have significant additional uncertainty.

11
12 This impact category should only be considered relevant if specific emission sources of
13 eutrophying substances are identified and linked to unit process(es) in the anthropogenic system
14 under study. These emissions sources must be described in the LCA report.

15
16 Sensitivity analysis can be used to help determine if eutrophying emissions can be linked to unit
17 process(es) in the anthropogenic system under study. If emissions of eutrophying substances are
18 reported in the LCI analysis, the significance of the emission should be determined by increasing
19 the scale of the functional unit. If, using the scaled up functional unit, the total emissions of
20 eutrophying substances across the entire anthropogenic system are negligible, this impact
21 category can be excluded as relevant.

22
23 **4.4.3. Classification.** Classification depends upon whether the affected receiving water body is
24 in exceedance of threshold for the primary or secondary symptoms of eutrophication, based on
25 the definitions in Section 5.4.1.1.

26
27 For category indicators characterizing contribution to eutrophication in a receiving water body
28 in exceedance of threshold for primary symptoms, emissions of all substances contributing to the
29 primary symptoms of eutrophication should be classified. This includes emissions of biologically-
30 available nitrogen and phosphorus compounds.

31
32 For category indicators characterizing contribution to eutrophication in a receiving water body
33 in exceedance of threshold for secondary symptoms, emissions of all substances contributing to
34 secondary symptoms of eutrophication should be classified. This includes emissions of
35 biologically-available nitrogen and phosphorus compounds, as well as organic chemicals
36 contributing directly to chemical and biological oxygen demand.

37
38 In classification for category indicators at either node, the controlling nutrient must also be
39 identified for a given receiving water body. Nitrogen and phosphorus are the main nutrients
40 controlling algae growth, and initially, compounds of both nitrogen and phosphorus should be
41 considered. Only the controlling nutrient should be classified. If no specific data is available, it
42 can be assumed that nitrogen is the limiting nutrient.

43
44 NOTE. The relative importance of nitrogen and phosphorus varies between different water bodies, and
45 can even vary in the same water body over time. In most marine systems, nitrogen is typically the limiting
nutrient. The limiting nutrient can be determined with N / P calculations.

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4.4.4. Characterization.

4.4.4.1. Potency Potential Characterization Factors. PP-CFs are separately defined for characterization of emissions of nutrients and oxygen depleting chemicals, based on the distinct nature of these stressors and the midpoints they effect. For nutrients, the PP-CF characterizes the potential contribution to algae formation, compared to the potential contribution to algae formation from the limiting nutrient (either nitrogen or phosphorus). For oxygen depleting chemicals, the PP-CF characterizes the potential contribution to depletion of oxygen.

In rare cases, emissions of both nutrients and oxygen depleting chemicals may be affecting the same receiving water body in exceedance of threshold for secondary eutrophication. In these cases, equivalencies must be established to aggregate nutrients and oxygen depleting chemicals using PP-CFs. The basis of such equivalencies must be described in the LCA report. If no equivalencies can be established using credible research, then aggregation is not possible, and separate indicators must be reported (see Section 5.4.2.1).

4.4.4.1.1. Characterization of Potential Contribution to Algae Formation. For nutrients, the PP-CF represents the potential contribution to algae formation of an emission, using the Redfield ratio.³² PP-CFs can be derived from peer-reviewed sources. PP-CFs based upon the Redfield ratio are shown in Table 5. 6 for receiving environments with different limiting nutrients.

Table 5. 3. PP-CF values, characterizing the Redfield ratio in environments with different limiting nutrients. Source: Table 6.1, Danish Guidelines^{33, 34}

Substance	Formula	PP-CF (Nitrogen-Limited Environment) kg N. eq. / kg substance	PP-CF (Phosphorus Limited Environment) kg P eq. / kg substance	PP-CF (Limiting Nutrient not determined) kg NO ₃ - eq. / kg substance
Nitrogen Compounds				
Ammonia	NH ₃	0.82	0	3.64
Nitrate	NO ₃ ⁻	0.23	0	1.00
Nitrite	NO ₂ ⁻	0.30	0	1.35
Cyanide	CN	0.54	0	2.38
Total Nitrogen	N	1.00	0	4.43
Phosphorus Compounds				
Phosphate	PO ₄ ³⁻	0	0.33	10.45
Pyrophosphate	P ₂ O ₇ ²⁻	0	0.35	11.41
Total Phosphorus	P	0	1.00	32.03

³² At this time, a method for computing PP-CFs for this indicator that is more accurate than use of the Redfield ratio has not been identified.

³³ M. Hauschild and Potting, J., 2003. Spatial differentiation in Life Cycle impact assessment - The EDIP2003 methodology. Institute for Product Development Technical University of Denmark.

³⁴ In situations where the limiting nutrient cannot be determined, the final column can be used.

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1 **4.4.4.1.2. Characterization of Potential Contribution to Depletion of Oxygen.** For oxygen
2 depleting chemicals, the PP-CF represents the potential contribution to depletion of oxygen
3 resulting from an emission. The PP-CF should be based on chemical oxygen demand (COD) or
4 biological oxygen demand (BOD) tests.

5 The COD test considers the amount of organic compounds in water, and is expressed in terms of
6 the mass of oxygen consumed per liter of solution (in units of mg/L). The BOD test measures the
7 amount of oxygen required for microorganisms to decompose organic matter, and is measured
8 in units of oxygen consumed per liter of solution (mg/L). Either basis is acceptable for the PP-CF
9 used in this indicator result.

10
11 Indicator results are reported in mass of oxygen demand, and so the PP-CF for this indicator is
12 computed as the mass of oxygen demand per mass of chemical emission. Either the COD or BOD
13 test can be used to evaluate this equivalency for specific chemicals.

14 **4.4.4.2. Midpoint Characterization Factors.** The M-CF represents the emissions transporting
15 into waters above exceedance of threshold, and so depends upon whether the characterization is
16 at Node 3 or 4 (representing contribution to symptoms of primary or secondary eutrophication,
17 respectively). The M-CF represents the fraction of emission of an eutrophying substance that is
18 transported into receiving waters in exceedance of threshold.

19
20 The M-CF is expressed on a scale of 0 to 1, with 1 representing 100 percent transport or
21 deposition in environments where thresholds are exceeded. In situations where emissions to soil,
22 water, and air are all occurring, M-CF values should be determined separately for each
23 compartment, to reflect differences in fate and transport.

24 **FOR EXAMPLE.** The M-CF for emissions to soil must account for the percent that runs off into waterways
25 and subsequently transports to the affected receiving water body.

26
27 Site-specific modeling techniques of fate and transport are required to assess the M-CF for
28 Eutrophication. When assessing M-CFs, published literature should be surveyed. Particularly in
29 regions subject to the regulation of emissions of eutrophying substances, government agencies
30 or other organizations may have established fate and transport models which can be used as the
31 basis of M-CFs. Whenever possible, this type of publicly available data should be retrieved and
32 used. The basis and data sources used to calculate M-CFs shall be described in the LCA report.

33 **FOREXAMPLE.** In the United States, the US Geological Survey has established the SPARROW Surface Water-
34 Quality Modeling tool, a publicly available modeling tool for the regional interpretation of water-quality
35 monitoring data. The SPARROW tool empirically estimates the origin and fate of contaminants in river
36 networks, including eutrophying substances, and quantifies uncertainties in model predictions. SPARROW
37 has been used to estimate the amount of phosphorus and nitrogen from emissions into the
38 Mississippi/Atchafalaya River Basins which transport to the eutrophied regions in the Gulf of Mexico. For
39 emissions of eutrophying substances into the Mississippi or Atchafalaya River watersheds, results from
40 SPARROW can be used to establish M-CFs for Eutrophication in the Gulf of Mexico.
41

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1 **4.4.5. Indicator Equation and Unit of Measure.** If the category indicator is at Node 3 or 4,
2 results are calculated using Equation 5.7. For emissions of nutrients, the results are reported in
3 units of mass of nitrogen or phosphorus equivalent, depending on the limiting nutrient.

4 If the category indicator is at Node 4, and emissions are organic chemicals which directly
5 contribute to oxygen depletion, the results are reported in units of mass of chemical or biological
6 oxygen demand.

7 **Equation 5.7. Indicator equation for a single unit process for Eutrophication, characterized at Node 3 or 4.**

$$\text{Eutrophication} = \sum_n \sum_j \text{Emissions}_{n,j} \times \text{PP-CF}_{n,j} \times \text{M-CF}_{n,j}$$

Where:

- *n is the total number of eutrophying emissions linked to the unit process*
- *j represents soil, water, and air emissions, which may have different M-CF values for a specific eutrophying emission*
- *Emissions represent the eutrophying emissions linked to the unit process, in units of mass*
- *PP-CF represents the Redfield ratio of the emitted substance, when compared to nitrogen or phosphorus (depending on the limiting nutrient), or the potential contribution to oxygen depletion*
- *M-CF represents the fraction of the emission which transports into regions which are in exceedance of threshold for eutrophication*

8 **4.4.6. Additional Reporting Requirements.** In the LCA report and EPDs or C-EPDs, any receiving
9 water bodies considered in category indicators for eutrophication (meeting the requirements of
10 Sections 5.4.2.1 and 5.4.2.2) shall be described. In this description, the location of the water body,
11 type of symptom experienced, and severity of eutrophication in exceedance of threshold should
12 be included. The category indicator name shall describe the receiving water body which is
13 affected.

14 **4.4.7. Addressing Additional Limitations in Types, Accuracy, and Availability of**
15 **Environmental Data.** The most important environmental data regards the fate and transport of
16 eutrophying substances. In some cases, there may not be data available to establish M-CFs for a
17 category indicator, even in cases where specific emissions sources of eutrophying substances
18 have been identified in the anthropogenic system under study, and linked to the contribution to
19 exceedances of threshold of eutrophication in specific receiving water bodies, according to the
20 requirements of Section 5.4.2.1 and 5.4.2.2. In these cases, results can be reported at Node 1 for
21 unit process(es) which are known to contribute to eutrophication.

22 If data is not available to characterize eutrophication, or to determine if it is a relevant impact
23 category, it may not be possible to achieve the goals of the LCA study. In these cases, the goal and
24 scope may need to be revised.

26 **4.5. Key Species Loss**

27
28 **This impact category** is linked to the loss of species in world oceans, being caused by a number
29 of different impact vectors, such as overfishing. The specific set of stressors, midpoints, and
30 endpoints, will depend upon the industry sector and affected species. This Standard does not

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1 specify requirements for accounting. If relevant, this impact category shall be listed in final
2 results, and results can be listed as “No data”.

3
4 If an LCA study is developed providing results for this impact category, the methodology and data
5 sources used to generate results shall be transparently reported in the LCA report, and should be
6 subject to peer review. PCRs should be developed for situations where this impact category is
7 relevant, in order to provide metrics for calculation of results.
8

9 **4.6. Persistent, Bioaccumulative, and Toxic Chemical Loading**

10
11 **4.6.1. Impact Category.** This impact category considers the impacts of persistent,
12 Bioaccumulative, and toxic (PBT) chemicals which, if emitted into the environment, can
13 transport to the oceans and lead to persistent contamination of receiving environments on
14 many scales. These PBTs, if contamination exceeds safe thresholds, can lead to risks of impacts
15 to flora and fauna. PBTs are emitted into air, soil or water, and can affect many types of
16 ecosystems, including freshwater, marine, and terrestrial. This impact category considers
17 impacts on marine systems.
18

19 Separate category indicators are defined for each PBT emitted by a unit process within the
20 anthropogenic system, which is known to transport and contaminate marine receiving
21 environments over safe thresholds. By far the most common is mercury and compounds. Due to
22 its persistence and mobility, mercury contamination is an issue at regional and global levels, in
23 both marine and freshwater environments.
24

25 In all studies, unless mercury emissions can be found to be not occurring, mercury emissions
26 shall be included as a relevant impact category.
27

28 **4.6.1.1. Definition of Persistent, Bioaccumulative, and Toxic Chemicals.** In this Standard,
29 PBT chemicals include those which are known to contaminate marine receiving environments,
30 including but not limited to: the water column (estuarine, pelagic, or otherwise); and sediments.
31 PBT chemicals in this standard include at least those chemicals and compounds subject to
32 reporting as a requirement of the US EPA Toxic Resources Inventory. Other PBT Chemicals can
33 also be included; those listed in Table 4.6 are not an exhaustive list.
34

Table 4.6. List of PBT Chemicals regulated under the US EPA Toxic Resources Inventory.

Chemical / Compound Name	CAS Number
Aldrin	309-00-2
Benzo(g,h,i)perylene	191-24-2
Chlordane	57-74-9
Dioxin and dioxin-like compounds	N/A
Heptachlor	76-44-8
Hexachlorobenzene	118-74-1
Isodrin	465-73-6
Lead	7439-92-1
Lead Compounds	N/A
Mercury	7439-97-6
Mercury Compounds	N/A
Methoxychlor	72-43-5
Octachlorostyrene	29082-74-4
Pendimethalin	40487-42-1

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Pentachlorobenzene	608-93-5
Polychlorinated biphenyl (PCBs)	1336-36-3
Polycyclic aromatic compounds (PACs)	N/A
Tetrabromobisphenol A	79-94-7
Toxaphene	8001-35-2
Trifluralin	1582-09-8

1 **4.6.1.2. Definition of Threshold Exceedance for PBT Chemical Loading.** For a given PBT, the
2 threshold is a concentration in soils or sediments. If emissions are found to be relevant in this
3 impact category (based on the requirements of Section 5.3.2.2), the threshold used, and basis of
4 the threshold, shall be described in the LCA report. For PBT Exposure Risks, regions in
5 exceedance of threshold are defined as those receiving environments where concentrations of a
6 PBT are above these defined critical thresholds.

7
8 In practice, it can be assumed that a PBT is present at concentrations exceeding safe thresholds
9 if it has been observed accumulating in the tissues of marine organisms which are present.

10 **FOR EXAMPLE.** Methylmercury is present as a contaminant in open ocean pelagic waters at concentrations
11 sufficient to bioaccumulate in fish tissue to levels which in many cases are unsafe for human consumption,
12 Mercury compounds, even when emitted far from marine environments, can transport through air and
13 water to contribute to this mercury contamination.

14
15 **4.6.2. Stressor-Effects Network.** The stressor-effects network for this impact category depends
16 upon the size, location, timing, duration, and nature, of an emission; the resulting scale, severity,
17 and reversibility of midpoints of affected PBT chemical loading will vary for many reasons. If PBT
18 chemical loading is considered relevant, the stressor effect network shall be described in the LCA
19 report.

20 **NOTE.** Due to its persistence and ubiquity in marine systems, mercury loading is always relevant.

21 **4.6.2.1. Selection of Category Indicator(s).** After identifying all emissions of PBTs which are
22 relevant in this impact category (see Section 4.6.2.2), distinct category indicators are defined.

23
24 To define these distinct category indicators, the stressor-effects network for each species of PBT
25 chemical found to be relevant should first be considered separately. Separate category indicators
26 shall be reported for each PBT chemical emitted under the following conditions:

- 27 • Midpoints in the stressor-effects network linked to the emission are distinct in spatial
28 extent, duration, severity of contamination, and species which could be exposed.
- 29 • The species affected are distinct, and toxic endpoints associated with exposure to each
30 chemical are distinct in their character, temporal duration, severity, persistence,
31 reversibility, or other considerations.
- 32 • The characterization model used to assess category indicator results (dependent upon data
33 availability) is distinct.

34 Aggregation of emissions of different PBT chemicals into a single category indicator must be done
35 with care; even emissions which occur at similar levels, at the same place and time, can lead to
36 cause-effects chains which are distinct. Aggregation is only possible if there are consistent

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1 measures of chemical toxicity available for use. If there is no scientific basis for aggregation of
2 multiple PBT chemicals using PP-CFs, separate category indicators must be reported.
3

4 The node selected to characterize PBT chemical loading is preferentially at Node 3, representing
5 the fraction of an emission contributing to the contamination of a receiving environment in
6 exceedance of threshold.
7

8 In practice, there is rarely sufficient data available to characterize results at Node 3.
9 Characterization at Node 2 should be used if possible. This characterizes the fraction of an
10 emission contributing to contamination of the receiving environment, irrespective of whether
11 contamination occurs above thresholds.
12

13 However, in many instances, characterization data will not be available for characterization
14 above Node 1, which characterizes emissions levels. Characterization at Node 1 has low
15 environmental relevance. The level of environmental relevance shall be described in the LCA
16 report, and wherever results are reported.
17

18 The category indicator for Mercury Loading, which shall always be reported, is reported simply
19 as Mercury Emissions. No aggregation with other PBT Chemicals is allowed. Existing fate and
20 transport models are not capable of projecting the long-term fate and transport of mercury
21 compounds, which can transit to marine environments and cause exposure years after emission.
22

23 The stressor-effects network shall be described in the LCA report. The specific midpoint of
24 contaminated receiving environment into which an emission transports must be described in the
25 LCA report and EPDs or C-EPDs; if multiple midpoints are occurring as a result of an emission, all
26 must be described.
27

28 Due to the close linkage between the stressor effects network for the initial nodes of HEC
29 Exposure Risks and HFWC Exposure Risks, in many cases, category indicators will be similar in
30 these two impact categories, and characterization models will be the same. If the initial nodes in
31 the stressor effects network are the same, and if characterization models are the same, then one
32 category indicator must be reported for both of these impact categories, to avoid double counting.
33 However, in the LCA report and EPDs or C-EPDs, the midpoints and endpoints relevant to both
34 impact categories shall be described.
35

36 **4.6.2.2. Identifying Core Impact Categories and Category Indicator(s).** Due to the extensive
37 data collection and analysis required to characterize category indicators for PBT chemical
38 loading, it is essential to carefully screen the anthropogenic system under study to identify unit
39 process(es) which are contributing to risks of exposure of flora/fauna to PBT chemicals over
40 defined thresholds. This screening is intended to minimize the amount of data collection
41 required.

42 NOTE. Although for a given study, characterization may be at Node 1, the determination of this
43 impact category as relevant is based on a screening of linkages to the midpoint at Node 3, representing the
44 risk of exposure to flora/fauna to PBTs in regions in exceedance of threshold.
45

46 This impact category should be considered relevant for a given PBT chemical emitted from a
47 single unit process, if the emission satisfies the following conditions:

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- 1 • The given PBT chemical has been detected as a contaminant in the local receiving
2 environment which is in exceedance of threshold defined in measurement of water
3 concentration or sediment concentration. In practice, this means considering local marine
4 receiving environments (e.g., estuaries) and the presence of emitted PBTs (see threshold
5 definitions in Section 4.6.1.2), *or*
- 6 • The given PBT chemical has been detected in the tissue of organisms present in the
7 receiving environment at unsafe levels, *and*
- 8 • The emission must be shown to contribute to the local instance of contamination.

9 Generally the most effective approach to screening is identifying if the given PBT chemical has
10 been detected in the tissue of organisms present in the receiving environment at unsafe levels.
11 This information is more readily available than measurements of concentrations in water or
12 sediments.

13 **4.6.3. Classification.** All emissions of PBT chemicals which are relevant for this impact category
14 according to the requirements of Section 4.6.2.2 are classified. Multiple category indicators may
15 be reported according to the requirements of Section 4.6.2.1.

16 **4.6.4. Characterization**

17 **4.6.4.1. Potency Potential Characterization Factors.** The PP-CF is determined by PBT
18 Chemical, and is separately defined for each category indicator included in the study scope
19 according to the requirements of Section 4.6.2.1.

20
21 Generally, PBT chemicals will be treated in separate category indicators. In these cases, PP-CFs
22 characterize the equivalent mass of the main active PBT in order to aggregate results.

23 **FOR EXAMPLE.** Emissions of mercury compounds are aggregated into results of Mercury Emissions (in
24 units of mass of elemental mercury) using PP-CFs characterizing the mass of elemental mercury per mass
25 of emission.

26
27 In cases where multiple PBT Chemicals are considered in a single category indicator, the PP-CF
28 characterizes the ecotoxicity of each PBT Chemical, compared to the ecotoxicity of a reference
29 contaminant. For each category indicator, the same reference contaminant, and consistent
30 measures of ecotoxicity, must be used. See Section 5.3.4.1 for an approach to characterize PP-CFs
31 in this fashion.

32
33 **4.6.4.2. Midpoint Characterization Factors.** For category indicators in this impact category,
34 three levels of reporting at three different nodes are possible, based upon the data availability.

35
36 For a given category indicator, the same characterization must be applied to all relevant
37 emissions of PBT Chemicals. Comparison between results calculated using different
38 characterization models is not possible. In LCA report, the characterization model used to derive
39 results must be described clearly wherever results are reported.

40
41 The three possible nodes which can be used for characterization are:

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- 1 • Node 3, characterizing the fraction of an emission which contributes to the contamination of
2 a receiving environment in exceedance of threshold (see Section 4.6.1.2).
- 3 • Node 2, characterizing the fraction of an emission which contributes to the contamination of
4 the receiving environment (irrespective of whether it is in exceedance of threshold).
- 5 • Node 1, characterizing the emissions level of the PBT Chemical (which shall be used to
6 assess Mercury Emissions).

7 The characterization models which can be used for these assessments are identical to those used
8 for Freshwater Ecotoxic Risks. See Section 5.3.4.2 for more information.

9
10 **4.6.5. Indicator Equation and Unit of Measure.** For this accumulated midpoint, results are
11 calculated using the equation below. Regardless of the node of characterization, results are
12 reported in units of mass equivalents of the reference substance.

13 **Equation 4.6. Indicator equation for PBT Chemical Loading.**

$$PBT\ Chemical\ Loading = \sum_j \sum_i (Emissions_i\ in\ year\ j \times PP-CF_i \times M-CF_j)$$

Where:

- Emissions are the emissions levels of a given PBT Chemical, reported in units of mass.
- j represents the total number of years in the LCA time horizon (for this accumulated midpoint)
- PP-CF is the Potency Potential Characterization Factor for each PBT Chemical.
- M-CF (if applied) is the Midpoint Characterization Factor.

14 **4.6.6. Additional Reporting Requirements.** In the LCA report and any EPDs or C-EPDs, the
15 midpoint of contaminated receiving environment in exceedance of threshold associated with a
16 category indicator shall be described.

17 The name of the category indicator used to assess results shall be clearly stated in the LCIA
18 profile. The name used shall clearly describe the modeling used, and not overstate the
19 environmental relevance of results.

20
21 Mercury Loading shall always be a relevant category indicator (provided mercury emissions
22 occur in the anthropogenic system).

23 **4.6.7. Addressing Additional Limitations in the Types, Accuracy and Availability of**
24 **Environmental Data.** The first step in characterization of results in this impact category is the
25 screening for determination of relevance of emissions. In some anthropogenic systems, where
26 unit process(es) in the anthropogenic system are distributed in extensive global supply chains,
27 lax regulations and poor monitoring in certain regions might make it impossible to determine the
28 relevance of specific emissions sources to this impact category. If the screening cannot be
29 conducted, then determination of the relevance of this impact category is not possible; this could
30 affect the ability to achieve the goals of the LCA study. If the relevance of this impact category
31 cannot be determined, the goal and scope of the LCA study may need to be revised.

32 In certain cases, although the scale of emission from a unit process may be unknown, the nature
33 and region of an emission occurring in the anthropogenic system under study will be understood,

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1 and there will be observational data which clearly shows that the emission contributes to the
2 active midpoint of contamination of a receiving environment in exceedance of threshold. In these
3 cases, the category indicator name shall be reported, with the midpoints and endpoints
4 described, although results cannot be assessed at any node.
5

6
7 **4.7. Cumulative Plastic Loading**
8

9 This impact category is linked to the accumulation of macro and micro-plastic in the world
10 oceans. The specific set of stressors, midpoints, and endpoints, will depend upon the industry
11 sector and its linkage to deposition of plastic trash in the oceans. This Standard does not specify
12 requirements for accounting. If relevant, this impact category shall be listed in final results, and
13 results can be listed as “No data”.
14

15 If an LCA study is developed providing results for this impact category, the methodology and
16 data sources used to generate results shall be transparently reported in the LCA report, and
17 should be subject to peer review. PCRs should be developed for situations where this impact
18 category is relevant, in order to provide metrics for calculation of results.
19
20
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1 **5. Terrestrial and Freshwater Ecosystem Impacts (from Emissions)**

2 **5.1 Regional Acidification**

3 **5.1.1. Impact Category.** This impact category represents the deposition of acids into terrestrial
4 and inland water receiving environments where the buffering capacity threshold of regional soils
5 and water bodies has been exceeded.

6
7 **5.1.1.1. Definition of Exceedance of Threshold.** For Regional Acidification, regions which are
8 in exceedance of threshold are defined as those for which the buffering capacity of soils and/or
9 freshwater water bodies has been exceeded.

10 **5.1.2. Stressor-Effects Network.** The stressor-effects network for Regional Acidification is
11 shown in Error! Reference source not found. of Annex B. The fate and transport of acidifying
12 emissions and subsequent deposition into regions in exceedance of threshold for regional
13 acidification (Nodes 2 and 3 in Error! Reference source not found. in Annex B) will vary based
14 upon the region of emission and other considerations. Accordingly, regional characterization is
15 necessary to assess accurate results. The use of representative data can help to guide
16 characterization, but could lead to significant uncertainties which may compromise the ability to
17 achieve the goals of the LCA study.

18 **5.1.2.1. Selection of Category Indicator.** The indicator for this impact category shall be at Node
19 3, if data is available, characterizing the fraction of an acidifying emission which deposits into
20 regions of exceedance of threshold for regional acidification. Generally, environmental data is
21 widely available on a global basis which can enable the dispersion modeling of Regional
22 Acidification at Node 3.

23 NOTE. Dispersion models such as the Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT)
24 model, developed initially through a joint effort by the US National Oceanic and Atmospheric
25 Administration and Australia's Bureau of Meteorology, are applicable globally. The data required are
26 globally gridded meteorological data for regular time intervals, which are generally widely available.

27 NOTE. The Harmonized World Soil Database provides over 15,000 different soil mapping units on a global
28 basis. This database combines regional and national updates of soil information worldwide.

29
30 In some instances, data will be unavailable to characterize Regional Acidification at Node 3. This
31 will occur in cases where the location of unit process(es) in the anthropogenic system with
32 acidifying emissions cannot be determined, or for other reasons. In these cases, the effect on final
33 results of the uncertainty which is introduced by the lack of data must be considered. Sensitivity
34 analysis can be used to explore the relevance of using representative data for M-CFs. If data
35 limitations for characterization at Node 3 result in significant inaccuracies which could
36 compromise the ability to achieve the goal of the LCA study, characterization at Node 3 may not
37 be possible.
38
39

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1 **5.1.2.2. Identifying Core Impact Categories and Category Indicator(s).** In practice, Regional
2 Acidification will be a relevant impact category for almost all anthropogenic systems. This is due
3 to the emissions of acidifying substances from combustion of coal, the main global source of
4 electricity generation. There are many other common sources of acidifying emissions which
5 could also contribute. If the scope of an LCA study includes coal-fired electricity generation, it can
6 be assumed that Regional Acidification will be a relevant impact category.

7
8 In practice, it should always first be assumed that Regional Acidification is a relevant impact
9 category.

10 **5.1.3. Classification.** All acidifying emissions to air are classified, including, but not limited to:
11 sulfur dioxide, sulfuric acid, nitrogen dioxide, nitric oxide, nitric acid, ammonia, hydrochloric acid,
12 hydrofluoric acid, hydrogen sulfide, and phosphoric acid.

13 **5.1.4. Characterization**

14 **5.1.4.1. Potency Potential Characterization Factors.** The PP-CFs represent the potential of
15 substances to release hydrogen ions into the receiving environment, compared to the potential
16 for sulfur dioxide to release hydrogen ions into the receiving environment. The PP-CFs for several
17 strong acids shown in Table 5. 1 can be used.

18 NOTE. The PP-CF therefore characterizes the theoretical maximum acidification of a substance, compared
19 to the theoretical maximum acidification of sulfur dioxide.

20
21 **Table 5. 1. Potential for release of hydrogen ions per kilogram of substance, compared to potential for release of hydrogen**
22 **ions per kilogram of sulfur dioxide. Source: EDIP97.³⁵**

Substance	Formula	kg SO _{2e} / kg substance
Ammonia	NH ₃	1.88
Hydrochloric acid	HCl	0.88
Hydrofluoric acid	HF	1.60
Hydrogen sulfide	H ₂ S	1.88
Nitric acid	HNO ₃	0.51
Nitric oxide	NO	1.07
Nitrogen dioxide	NO ₂	0.70
Phosphoric acid	H ₃ PO ₄	0.98
Sulfur dioxide	SO ₂	1.00
Sulfuric acid	H ₂ SO ₄	0.65

23
24

³⁵ Environmental Design of Industrial Products (EDIP), in Danish UMIP. 1996.

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1 **5.1.4.2. Midpoint Characterization Factors. The M-CF is the fraction of an emission which**
2 **deposits into sensitive regions, which are** defined as regions in Sensitivity Classes 1-4 (plus
3 fresh water) according to the Harmonized World Soil Database.³⁶ The M-CF is the fraction of
4 acidifying emissions which deposit into receiving environments that are in exceedance of
5 threshold for regional acidification. The M-CF is expressed on a scale of 0 to 1, with 1
6 representing 100 percent deposition in environments where thresholds are exceeded.
7

8 The M-CF differs by process in the supply chain. To determine the fraction of emissions which
9 deposit into sensitive soils, dispersion modeling shall be used. This dispersion modeling should
10 use mathematical and numerical techniques to simulate the physical and chemical processes that
11 affect substances that may disperse and react in the atmosphere, based on inputs of
12 meteorological data and source information. The dispersion model which is selected for use
13 should be publicly available, and derived from peer-reviewed work.³⁷ Hybrid Single Particle
14 Lagrangian Integrated Trajectory (HYSPLIT) dispersion model is one model which can be used.
15 ³⁸

17 NOTE. Dispersion models which are used can include those used in regulatory applications by air quality
18 management agencies and by other organizations, such as those used in the United States to determine
19 compliance with National Ambient Air Quality Standards.

20 NOTE. The US Environmental Protection Agency provides guidance and support for the use of numerous
21 air quality models through the Technology Transfer Network at the Support Center for Regulatory
22 Atmospheric Modeling. This guidance is periodically updated and revised to ensure the new model
23 developments or expanded regulatory requirements are incorporated. Access to the descriptions of air
24 dispersion models routinely used in air quality management studies can be found at the website of the US
25 EPA's Support Center for Regulatory Atmospheric Modeling.
26

27 This dispersion modeling must characterize deposition into regions that are beyond exceedance
28 of threshold for Regional Acidification, using maps of exceedance zones. This mapping requires
29 the specification of the soil sensitivity characteristics in order to determine the buffering capacity
30 within the receiving environment(s) affected by unit process(es) in the anthropogenic system
31 under study. This mapping can include the parameters such as the organic carbon content, pH,
32 water storage capacity, soil depth, cation exchange capacity of the soil and clay fraction, total
33 exchangeable nutrients, lime and gypsum contents, sodium exchange percentage, salinity,

³⁶ Kuylenstierna, J.C.I., Henning Rodhe, Steve Cinderby and Kevin Hicks. Acidification in Developing Countries: Ecosystem Sensitivity and the Critical Load Approach on a Global Scale. *Ambio*, Vol. 30, No. 1 (Feb., 2001), pp. 20-28.
<http://www.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/index.html>.

³⁷ Dispersion models which can be used include those used in regulatory applications by air quality management agencies and by other organizations, such as those used in the United States to determine compliance with National Ambient Air Quality Standards. The US Environmental Protection Agency provides guidance and support for the use of numerous air quality models through the Technology Transfer Network at the Support Center for Regulatory Atmospheric Modeling. This guidance is periodically updated and revised to ensure the new model developments or expanded regulatory requirements are incorporated. Access to the descriptions of air dispersion models routinely used in air quality management studies can be found at the website of the US EPA's Support Center for Regulatory Atmospheric Modeling.

³⁸ National Oceanic and Atmospheric Administration: Air Resources Laboratory. HYSPLIT - Hybrid Single Particle Lagrangian Integrated Trajectory Model. <http://ready.arl.noaa.gov/HYSPLIT.php>

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1 textural class, and granulometry. The specific determination of how exceedance zones are
2 defined using available data shall be described in the LCA report.

3 Assessment of M-CFs should not be completed for all operations in the supply chain, as this is
4 impractical. Instead, M-CFs should be assessed using the following specific approach, in order to
5 minimize the effort required:

- 6 • After the initial LCI model is completed, LCA results shall be assessed using PP-CFs with no
7 M-CFs. No regionalization is required.
- 8 • The key unit processes (i.e., processes contributing over 15% to results) should be
9 identified based on results using PP-CFs.
- 10 • M-CFs should then be evaluated only for the key unit processes defined based upon PP-CFs,
11 in order to assess final results. M-CFs need not be evaluated for key unit processes which
12 are known to be in regions without sensitive soils. Additionally, M-CFs can be assessed for
13 unit processes known to be in regions with a high preponderance of sensitive soils, but are
14 not key unit processes based on PP-CFs.
- 15 • With this approach, typically 5-10 M-CFs need to be evaluated for each supply chain in
16 order to assess results of acceptable data quality.
- 17 • For the processes for which M-CFs are not established, conservative estimates can be used
18 to establish results. Uncertainty and data quality analysis can further assist in the effort to
19 minimize the number of M-CFs which are established.

20 **NOTE.** The set of key unit processes should be re-evaluated once final indicator results are calculated using
21 M-CFs based on **Error! Reference source not found.**

22 If it is not possible to assess M-CFs, then results cannot be reported for this category indicator.
23 The fraction of acid emissions depositing in sensitive soils varies from 5-95% around the world,
24 and results expressed without considering these differences can be very misleading.

25
26
27
28
29 **5.1.5. Indicator Equation and Unit of Measure.** The category indicator result (at Node 3) for
30 Regional Acidification is shown in Equation 5.1, for a single unit process. The indicator result is
31 expressed in units of mass of sulfur dioxide equivalent (SO₂e).

32 **Equation 5.1. Indicator equation for a single unit process for Regional Acidification, characterized at Node 3 (deposition**
33 **of acids into regions in exceedance of threshold for Regional Acidification).**

$$\text{Regional Acidification} = \sum_n (\text{Emissions}_n \times \text{PP-CF}_n \times \text{M-CF})$$

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Where:

- *Emissions represent the acidifying substances emitted by the unit process, in units of mass*
- *n is the total number of acidifying substances emitted by the unit process*
- *PP-CF represents the potential for release of hydrogen ions from the emitted substance, when compared to sulfur dioxide*
- *M-CF represents the fraction of the emission which deposits into regions which are in exceedance of threshold for regional acidification*

1 **5.2. Stratospheric Ozone Depletion**

2 **5.2.1. Impact Category.** This impact category represents the potential depletion of the
3 stratospheric ozone layer caused by specific releases of various ozone depleting substances
4 (ODSs) from unit process(es) in the anthropogenic system under study.

5 **5.2.2. Stressor-Effects Network.** The stressor-effects network involves the release of ODSs into
6 the atmosphere which, when transported to the stratosphere, react with stratospheric ozone,
7 causing a net reduction in stratospheric ozone concentrations. These reduced concentrations
8 lead to increased ultraviolet (UV) radiation reaching the Earth's surface, which can cause a
9 variety of impacts on human health and the environment (see Error! Reference source not found.
10 2 of Annex B).

11
12 **5.2.2.1. Selection of Category Indicator.** The indicator for this impact category is at Node 2.
13 Environmental data is readily available to characterize results, which shall not be at a lower node.
14

15 **5.2.2.2. Identification of Core Impact Categories and Category Indicator(s).** In practice, since
16 the signing of the Montreal Protocol, emissions of ODSs have been reduced significantly globally.
17 For almost all applications, ODSs have been almost entirely phased out in favor of non-ozone
18 depleting substances. Unless emissions of ODSs from specific unit process(es) in the
19 anthropogenic system are observed, this impact category will not be relevant. In practice, it can
20 usually be assumed that Stratospheric Ozone Depletion is not a relevant impact category. If it is
21 included as relevant, the justification for its inclusion shall be provided in the LCA report, and
22 should be included in any EPDs or C-EPDs.
23

24 Care should be taken in interpreting outputs from LCI models when using secondary inventory
25 data from commercially available databases. These models include the use of representative data
26 for unit process(es) far "upstream", which may include outdated datasets which include
27 emissions of ODSs. Results in the LCI analysis of ODSs may be an output from LCA software
28 models, but are in fact an artifact of the databases and model outputs. This impact category
29 should only be considered relevant if specific ODS emission sources are identified. These specific
30 emissions sources must be described in the LCA report.
31

32 Sensitivity analysis can be used to help determine if ODS emissions can be linked to the
33 anthropogenic system under study. If emissions of ODSs are reported in the LCI analysis, the
34 significance of the emission should be determined by increasing the scale of the functional unit
35 significantly. If, using the scaled up functional unit, the total emissions of ODSs are negligible, and
36 would not be detectable given typical measurement uncertainty at the scale considered, this
37 impact category can be excluded as relevant.

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1 **FOR EXAMPLE.** In a study of a fabricated steel product made in North America, the functional unit is
2 assessed for ton of product. At this scale of functional unit, the total ODS emissions (measured using Ozone
3 Depletion Potentials) is roughly one microgram (10^{-9} kilograms) of CFC-11 equivalent. To determine if
4 Stratospheric Ozone Depletion is relevant, the results were scaled to the total annual production of the
5 steel product in North America, roughly 1,000,000 tons per year. At this scale of functional unit, the
6 emissions levels of ODSs from the anthropogenic system are roughly 10 kilograms. Considering that at the
7 national scale, the confidence interval regarding emissions of ODSs is on the order of $\pm 1,000$ or $\pm 10,000$
8 tons of CFC-11,^{39,40} an indicator result for national steel production showing result of 10 kilograms CFC-11
9 equivalent is far below current measurement thresholds. This impact category was not relevant.

10 **5.2.3. Classification.** All substances on a list of ozone depleting substances established by the
11 1987 Montreal Protocol are classified as ODSs.

12 **5.2.4. Characterization**

13 **5.2.4.1. Potency Potential Characterization Factors.** The Potency Potential Characterization
14 Factor for an ODS is the Ozone Depletion Potential (ODP) established under the Montreal
15 Protocol.
16

17 **5.2.4.2. Midpoint Characterization Factors.** The category indicator is at Node 2, characterized
18 using PP-CFs based upon the Ozone Depletion Potential. There is no M-CF.

19 **5.2.5. Indicator Equation and Unit of Measure.** The equation for calculating results for
20 Stratospheric Ozone Depletion is shown in Equation 5.2. The result is reported in units of mass
21 of CFC-11 equivalent, using ODPs.

22 **Equation 5.2. Indicator equation for assessing results for a single unit process for stratospheric ozone depletion, at Node**
23 **2.**

$$\text{Stratospheric Ozone Depletion} = \sum_j \sum_n (\text{Emissions in year } j \times \text{ODP}_n)$$

Where:

- *j represents the total number of years in the LCA time horizon (for this accumulated midpoint)*
- *n represents the total number of ODSs emitted by the unit process*
- *ODP_n represents the Ozone Depletion Potential of the ODS n*
- *Emissions are in units of mass*

24 **5.3. Freshwater Ecotoxic Exposure Risks**

25 **5.3.1. Impact Category.** This impact category considers releases of hazardous environmental
26 contaminants (HECs) from unit process(es) in the anthropogenic system, which can lead to risks

³⁹ XingQin, AN, et al. *Estimating emissions of HCFC-22 and CFC-11 in China by atmospheric observations and inverse modeling*. Science China: Chemistry. 2012.

⁴⁰ McCulloch, A. *Review of CFC-11: Metadata on Distributed Emissions*. Based on McCulloch A., P. Ashford and P.M. Midgley Historic Emissions of Fluorotrichloromethane (CFC-11) Based on a Market Survey Atmos. Environ., 35(26), 4387-4397, 2001. Retrieved on 11/6/2013 from <http://www.geiacenter.org/sites/default/files/site/dataset/Reviews-Old/CFC-11%20Review%20%26%20Data.pdf>

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1 of exposure to flora and fauna. These HECs are emitted into air, soil or water, and can affect many
2 types of ecosystems, including freshwater, marine, and terrestrial. However, through fate and
3 transport, usually freshwater ecosystems are affected.

4 The emissions which are relevant to this impact category are usually chemicals which have long
5 residence times in the environment. HECs can result in chronic exposures to flora and fauna,
6 which may occur after fate and transport through multiple media, and may occur years after an
7 emission occurs. However, in some instances, significant continuous emission sources of
8 chemicals with relatively short residence times can lead to steady-state concentrations of HECs
9 in the receiving environment, leading to a risk of exposure to flora and fauna.

10
11 The severity, spatial scale, and reversibility, of risks to flora and fauna associated with emissions
12 of different HECs from different unit processes will vary broadly, depending on factors such as
13 the HEC emitted, scale of emission, timing of emission, duration of emission, medium of emission,
14 and regional setting. The midpoints and endpoints associated with this impact category vary for
15 all of these reasons. Accordingly, site-specific assessment of HEC Exposure Risks is required.
16 Secondary data shall not be used in the assessment of this impact category.
17

18 **5.3.1.1. Definition of Hazardous Environmental Contaminant.** In general, HECs are those
19 substances with proven linkages between emissions, exposure to flora/fauna, and onset of chronic
20 or acute toxic effects in sensitive species. These chemicals are considered hazardous and are included
21 for consideration in this impact category, subject to the requirements of Section 5.3.2.2.
22

23 At the outset of the study, the set of HECs considered should be clearly defined. For a given LCA
24 study, the set of HECs will be screened to identify those emission sources which have emissions
25 which are relevant for HEC Exposure Risks (see Section 5.3.2.2).
26

27 To establish a set of HECs, published lists of chemicals which have been observed in the
28 environment at concentrations above defined thresholds (regulatory thresholds, or otherwise)
29 should be investigated. Lists of chemicals which are targeted for regulation or remediation
30 should be consulted first, as this is a strong indication that exposure has occurred in flora and
31 fauna.
32

33 For the United States, lists have been established by the US National Oceanic and Atmospheric
34 Administration (NOAA), for use in the Sediment Quality Guidelines, and are regulated under the
35 US EPA Toxic Resources Inventory. The chemicals are shown in Table 5. 4. This list of chemicals
36 shall be used at a minimum as the basis for a list of HECs. However, additional HECs may exist
37 and be relevant.
38

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1
2
3

Table 5. 4. The list of substances covered by NOAA’s Sediment Quality Guidelines and US EPA Toxic Resource Inventory. ^{41,42;43}

Heavy Metals	Polychlorinated biphenyls (PCB)
Arsenic	Chlordane
Cadmium	Dieldrin
Chromium	DDD
Copper	DDE
Lead and Compounds	DDT
Mercury and Compounds	Endrin
Nickel	Other Chemicals
Silver	Aldrin
Zinc	Benzo(g,h,i)perylene
Polycyclic Aromatic Hydrocarbons (PCH)	Chlordane
Acenaphthene	Dioxin and dioxin-like compounds
Acenaphthylene	Heptachlor
Anthracene	Hexachlorobenzene
Fluorene	Isodrin
2-Methyl naphthalene	Methoxychlor
Low-molecular weight PAH	Octachlorostyrene
Benz(a)anthracene	Pendimethalin
Benzo(a)pyrene	Pentachlorobenzene
Crysene	Tetrabromobisphenol A
Dibenzo(a,h)anthracene	Toxaphene
Fluoranthene	Trifluralin
Pyrene	
High molecular weight PAH	

4
5
6
7

For a given unit process, other hazardous chemicals may be relevant in this impact category than are included in Table 5. 4.

⁴¹ NOAA. Sediment Quality Guidelines Developed for the National Status and Trends Program. Released 6/12/99. See http://response.restoration.noaa.gov/book_shelf/121_sedi_qual_guide.pdf

⁴² MacDonald, D.D., C.G. Ingersoll, T.A. Berger. Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems. Arch. Environ.

⁴³ <https://www.epa.gov/toxics-release-inventory-tri-program/persistent-bioaccumulative-toxic-pbt-chemicals-covered-tri>

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1 **5.3.1.2. Definition of Threshold Exceedance for HEC Exposure Risks.** For a given HEC, the
2 threshold is a concentration in a specific medium, usually water. If emissions are found to be
3 relevant in this impact category (based on the requirements of Section 5.3.2.2), the threshold
4 used, and basis of the threshold, shall be described in the LCA report. For HEC Exposure Risks,
5 regions in exceedance of threshold are defined as those receiving environments where
6 concentrations of a HEC are above these defined critical thresholds.

7
8 The threshold used shall be defined by HEC, and must be based upon a quantitative, measurable
9 value representing the concentration level resulting in onset of the critical toxic effect in sensitive
10 flora or fauna, taking into account as many species and as many taxonomic groups as possible.

11
12 The definition of the threshold can be based on the tenth percentile value of concentrations which
13 have been observed to result in the critical toxic effect in flora and fauna. The concentration and
14 approach used to define the exceedance of threshold for a given HEC shall be clearly described
15 and justified in the report, along with data sources.

16
17 NOTE. The Effects Range-Low (ERL) values, published by the National Oceanic and Atmospheric
18 Administration (NOAA), can be used to determine the threshold concentration for a given HEC. ERL values
19 are established for heavy metals and several persistent organic substances, and have been used in the
20 Sediment Quality Guidelines used by NOAA.⁴⁴

21
22 If multiple HECs are present in the receiving environment (i.e., as mixtures), combined exposure
23 could result in impacts to exposed species, even if no individual HEC is present at concentrations
24 over its specific threshold. When considering if a region is in exceedance of threshold, the effect
25 of mixtures of HECs must be considered.

26 **5.3.2. Stressor-Effects Network.** The stressor effects network, shown in Error! Reference
27 source not found.3 of Annex B, provides a general framework; however, for each separate
28 indicator included for HEC Exposure Risks within the study scope, a separate stressor-effects
29 network should be modeled. This model should describe the site-specific circumstances of
30 stressors, midpoints, and endpoints, in the cause-effect relationship resulting from the classified
31 emission source. This will greatly aid in the characterization of results.

32 The midpoint of the contamination of the receiving environment over thresholds (Node 3 in
33 **Error! Reference source not found.**3 in Annex B) is directly linked to the risk of exposures of
34 flora/fauna. For receiving environments which are contaminated, the contaminants, spatial scale,
35 persistence, and level of contamination, should be understood. Contaminated receiving
36 environments may be linked to emissions occurring at unit process(es) considered in the
37 anthropogenic system under study, but may also be linked with unit processes outside of the
38 scope of the LCA. Accordingly, it is important to understand other emissions sources which are
39 contributing to this midpoint.

⁴⁴ NOAA. Sediment Quality Guidelines Developed for the National Status and Trends Program. Released 6/12/99. See http://response.restoration.noaa.gov/book_shelf/121_sedi_qual_guide.pdf

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1 The emissions which are relevant to this impact category may also be linked to stressor effects
2 networks for Hazardous Food or Water Contaminant Exposure Risks, since the midpoints at Node
3 2 and 3 (contamination of the receiving environment) are similar.
4

5 **5.3.2.1. Selection of Category Indicator(s).** After identifying all emissions of HECs which are
6 relevant in this impact category (see Section 5.3.2.2), distinct category indicators are defined.
7

8 To define these distinct category indicators, the stressor-effects network for each species of HEC
9 found to be relevant should first be considered separately. Separate category indicators shall be
10 reported for each HEC emitted under the following conditions:

- 11 • Midpoints in the stressor-effects network linked to the emission are distinct in spatial
12 extent, duration, severity of contamination, and species which could be exposed.
- 13 • Where multiple types of ecosystems are affected, representing distinct environmental
14 mechanisms (i.e., for freshwater, marine, and terrestrial ecosystems).
- 15 • The species affected are distinct, and toxic endpoints associated with exposure to each
16 chemical are distinct in their character, temporal duration, severity, persistence,
17 reversibility, or other considerations.
- 18 • The characterization model used to assess category indicator results (dependent upon data
19 availability) is distinct.

20 Aggregation of emissions of different HECs into a single category indicator must be done with
21 care; even emissions which occur at similar levels, at the same place and time, can lead to cause-
22 effects chains which are distinct. Aggregation is only possible if there are consistent measures of
23 ecotoxicity available for use. If there is no scientific basis for aggregation of multiple HECs using
24 PP-CFs (see Section 5.3.4), separate category indicators must be reported.
25

26 The node selected to characterize HEC Exposure Risks, is preferentially at Node 3, representing
27 the fraction of an emission contributing to the contamination of a receiving environment in
28 exceedance of threshold.
29

30 In practice, there is rarely sufficient data available to characterize results at Node 3.
31 Characterization at Node 2 should be used if possible. This characterizes the fraction of an
32 emission contributing to contamination of the receiving environment, irrespective of whether
33 contamination occurs above thresholds.
34

35 However, in many instances, characterization data will not be available for characterization
36 above Node 1, which characterizes emissions levels. Characterization at Node 1 has low
37 environmental relevance. The level of environmental relevance shall be described in the LCA
38 report, and wherever results are reported.
39

40 The stressor-effects network shall be described in the LCA report. The specific midpoint of
41 contaminated receiving environment into which an emission transports must be described in the
42 LCA report and EPDs or C-EPDs; if multiple midpoints are occurring as a result of an emission, all
43 must be described.

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1
2 Due to the close linkage between the stressor effects network for the initial nodes of HEC
3 Exposure Risks and HFWC Exposure Risks, in many cases, category indicators will be similar in
4 these two impact categories, and characterization models will be the same. If the initial nodes in
5 the stressor effects network are the same, and if characterization models are the same, then one
6 category indicator must be reported for both of these impact categories, to avoid double counting.
7 However, in the LCA report and EPDs or C-EPDs, the midpoints and endpoints relevant to both
8 impact categories shall be described.
9

10 **5.3.2.2. Identifying Core Impact Categories and Category Indicator(s).** Due to the extensive
11 data collection and analysis required to characterize category indicators for HEC Exposure Risks,
12 it is essential to carefully screen the anthropogenic system under study to identify unit
13 process(es) which are contributing to risks of exposure of flora/fauna to HECs over defined
14 thresholds. This screening is intended to minimize the amount of data collection required.

15 NOTE. Although for a given study, characterization may be at Node 1, the determination of this
16 impact category as relevant is based on a screening of linkages to the midpoint at Node 3, representing the
17 risk of exposure to flora/fauna to HECs in regions in exceedance of threshold.
18

19 This impact category should be considered relevant for a given HEC emitted from a single unit
20 process, if the emission satisfies two conditions:

- 21 • The given HEC has been detected as a contaminant in the local receiving environment which
22 is in exceedance of threshold (see Section 5.3.1.2).
- 23 • The emission must be shown to contribute to the local instance of contamination.

24 As part of the iterative process, those unit process(es) in the anthropogenic system which result
25 in significant emissions of HECs should be identified; it can then be determined if these emissions
26 are occurring in regions where the HEC in question occurs in the local receiving environments in
27 exceedance of threshold. Monitoring data of contaminant concentrations is often readily
28 available from governmental monitoring programs or in published literature.
29

30 This screening should consider the gross scale of emissions levels occurring in a anthropogenic
31 system conservatively, based on total annual emissions from specific unit process(es) of concern.
32 If emissions levels of a specific HEC are negligible even using conservative assumptions, the
33 emission will not be relevant in this impact category. An efficient screening will require expert
34 judgment to guide the iterative process.
35

36 When conducting this screening, it is important to identify types of unit process(es) which have
37 been known in the other cases to have emissions which contribute measurably to risks of
38 exposure to flora/fauna to HECs in receiving environments which are in exceedance of threshold.
39 This can include consideration of: unit processes by type, when similar unit processes are known
40 to emit HECs which cause contamination of receiving environments; the HEC and region of
41 emission, if the HEC is a widespread contaminant in the receiving environment where the unit
42 process is located; or the regulatory setting in which a unit process is located, if emissions
43 controls in the region where it is located are lax.
44

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1 Unit process(es) located in regions where contamination of local receiving environment(s) is an
2 issue of concern to regional government agencies and or other stakeholders, should also be
3 identified.
4

5 In many cases, the most significant emissions contributing to HEC Exposure Risks will occur far
6 “upstream” in the anthropogenic system under study. These significant emission sources often
7 occur in small unit operations in overseas regions, subject to lax emissions controls. A thorough
8 screening of the available literature can help to determine if such unit processes exist in the
9 anthropogenic system under study.
10

11 The persistence of the HEC which is emitted by a unit process should be considered, to help
12 identify emissions which could present a risk of exposure to flora/fauna in the long term.
13 Measures of the persistence of an HEC should consider its chemical half-life or elimination time
14 in different media (e.g., soil, sediments, water).
15

16 The level of emission of an HEC should also be understood in the context of the local receiving
17 environment. In some cases, emissions of HECs with relatively short environmental lifetimes can
18 still lead to increased steady-state concentrations of the receiving environment, if the emissions
19 are maintained continuously at high levels.

20 **FOR EXAMPLE.** In the United States, atrazine is a widely used herbicide which has a relatively short half-
21 life in most receiving environments, due its tendency to chemically decompose in sunlight. However, due
22 to substantial volumes of application of atrazine for agricultural purposes in the Midwestern US, atrazine
23 occurs at elevated concentrations in surface water across much of the region.⁴⁵
24

25 Care should be taken to ensure that this impact category is not mistakenly identified as relevant.
26 HEC Exposure Risks can be ruled out as a relevant impact category if there are no unit process(es)
27 in the anthropogenic system which contribute measurably to the risk of exposure to flora/fauna
28 to HECs in receiving environments which are in exceedance of threshold. The justification for the
29 inclusion or exclusion of this impact category shall be provided in the LCA report.
30

31 When screening to determine if HEC Exposure Risks is a core impact category, the scale of the
32 functional unit used shall be large enough to include emissions transporting to contaminated
33 receiving environments in exceedance of threshold; the functional unit must not be set arbitrarily
34 low, which could rule out this impact category even in cases where risks of exposure to
35 flora/fauna are occurring and can be linked to emissions from a unit process in the anthropogenic
36 system. This screening will take care, and may require sensitivity analysis.
37

38 An initial screening for the relevance of this impact category may determine that the scale of the
39 functional unit may need to be revised, or that goal and/or scope may need to be revised in other
40 ways. The exclusion of this a core impact category should be a key subject of the critical review
41 phase.
42

⁴⁵ See United States Geological Survey: Watershed Regressions for Pesticides (WARP) Atrazine Model.

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1 NOTE. Although results from LCI models may indicate that the number of HECs emitted from a
2 anthropogenic system is significant, in practice, very few emissions will be of a nature and scale that risks
3 of exposure to flora/fauna will result.

4 **5.3.3. Classification.** All emissions of HECs which are relevant for this impact category according
5 to the requirements of Section 5.3.2.2 are classified. Multiple category indicators may be reported
6 according to the requirements of Section 5.3.2.1.

7 **5.3.4. Characterization**

8 **5.3.4.1. Potency Potential Characterization Factors.** The PP-CF is determined by HEC, and is
9 separately defined for each category indicator included in the study scope according to the
10 requirements of Section 5.3.2.1.

11
12 In cases where multiple HECs are considered in a single category indicator, the PP-CF
13 characterizes the ecotoxicity of each HEC, compared to the ecotoxicity of a reference
14 contaminant. For each category indicator, the same reference contaminant, and consistent
15 measures of ecotoxicity, must be used.

16 NOTE. For category indicators which include emissions of a single HEC, the HEC is its own reference
17 contaminant, and results are expressed in mass of the emission.

18
19 The PP-CF for this impact category is shown in Equation 5.3.

20 **Equation 5.3. Potency Potential Characterization Factor for HEC Exposure Risks.**

$$S - CF_i = \frac{eco\ toxicity_i}{eco\ toxicity_{reference}}$$

Where:

- *PP-CF is the Potency Potential Characterization Factor for a given HEC, denoted i*
- *Eco toxicity is the measure of the eco toxicity for the given HEC (denoted i), and the reference contaminant.*

21 NOTE. Results of emissions levels multiplied with the PP-CF shall give results in units of equivalent
22 mass of the reference contaminant. The PP-CF equation will thus depend upon the units of the measures
23 of ecotoxicity which are used.

24
25 The relative ecotoxicity of a HEC should be based upon a quantitative, measurable value
26 representing the concentration level resulting in onset of the critical toxic effect in sensitive flora
27 or fauna, taking into account as many species and as many taxonomic groups as possible. The
28 definition of the threshold can be based on the tenth percentile value of concentrations which
29 have been observed to result in the critical toxic effect in flora and fauna (rather than the mean
30 value). The basis of values of the relative ecotoxicity of different HECs shall be clearly described
31 and justified in the report, along with data sources.

32
33 The Effects Range-Low (ERL) values, published by the National Oceanic and Atmospheric
34 Administration (NOAA), can be used to determine the relative ecotoxicity for some HECs. ERL

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1 values are established for heavy metals and several persistent organic substances, and have been
2 used in the Sediment Quality Guidelines used by NOAA.⁴⁶

3
4 For some HECs, ERL values may not be available. In these cases, extreme care must be taken in
5 how the ecotoxicity of different HECs is established, in order to provide a defensible basis of
6 aggregation for multiple HECs included in a single category indicator. If there is no scientifically
7 defensible basis for assessing PP-CFs for multiple HECs based on consistent measures of
8 ecotoxicity, there is no way to aggregate emissions into a single category indicator. In these cases,
9 separate category indicators must be reported for each emission.

10
11 When deriving PP-CFs, the uncertainty in the measures of ecotoxicity which are used must be
12 considered in the context of the goal and scope of the study. The resulting data quality of the PP-
13 CF, and effect on the data quality of the final result for HEC Exposure Risks, must be described in
14 the LCA report.

15
16 If the uncertainty in the PP-CFs which are calculated are very high, it may not be possible to
17 achieve the goal(s) of the study. In these cases, the goal and scope may need to be revised.
18 Alternatively, final results can be expressed using a confidence interval.

19
20 **5.3.4.2. Midpoint Characterization Factors.** For category indicators in this impact category,
21 three levels of reporting at three different nodes are possible, based upon the data availability.

22
23 For a given category indicator, the same characterization must be applied to all relevant
24 emissions of HECs. Comparison between results calculated using different characterization
25 models is not possible. In LCA report, the characterization model used to derive results must be
26 described clearly wherever results are reported.

27
28 The three possible nodes which can be used for characterization are:

- 29
- 30 • Node 3, characterizing the fraction of an emission which contributes to the contamination of
a receiving environment in exceedance of threshold (see Section 5.3.1.2).
 - 31 • Node 2, characterizing the fraction of an emission which contributes to the contamination of
32 the receiving environment (irrespective of whether it is in exceedance of threshold).
 - 33 • Node 1, characterizing the emissions level of the HEC.

34 The characterization models used for assessment at each node are described in the sections
35 below.

36
37 **5.3.4.2.1. Characterization of Contribution to Contamination of Receiving Environments**
38 **in Exceedance of Threshold.** The M-CF assesses the fraction of an HEC emission which
39 contributes to contamination of a receiving environment which is in exceedance of threshold. At
40 Node 3, the characterization model used is the most environmentally relevant measure which is

⁴⁶ NOAA. Sediment Quality Guidelines Developed for the National Status and Trends Program. Released 6/12/99. See http://response.restoration.noaa.gov/book_shelf/121_sedi_qual_guide.pdf

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1 possible given current techniques. However, the characterization must integrate modeling of
2 the fate, transport, and accumulation of each HEC which is emitted, and may require significant
3 modeling resources to complete.

4 The uncertainty inherent in the modeling of fate and transport of HECs throughout the receiving
5 environment shall be considered when characterizing results for this indicator. Uncertainty
6 levels should be described in the LCA report and EPDs or C-EPDs, preferably as a confidence
7 interval. The modeling uncertainty may be significant enough that the goal of the LCA study
8 cannot be achieved. In these cases, the goal and scope may need to be revised, or the
9 characterization of results must be at a lower node which has less associated uncertainty.

10
11 The severity, spatial scale, and reversibility, of receiving environment contamination associated
12 with different emissions from different unit processes will vary broadly, depending on factors
13 such as the HEC emitted, scale of emission, timing of emission, duration of emission, medium of
14 emission, and regional setting. Associated midpoints and endpoints associated vary for all of
15 these reasons. Accordingly, site-specific assessment at this node is required. Secondary data shall
16 not be used in the characterization.

17
18 **5.3.4.2.2. Characterization of Contribution to Contamination of Receiving Environments.**

19 The M-CF assesses the fraction of an HEC emission which contributes to contamination of the
20 receiving environment, irrespective of whether the receiving environment is in exceedance of
21 threshold. The characterization must integrate modeling of the fate, transport, and
22 accumulation of each HEC which is emitted.

23
24 The uncertainty inherent in the modeling of fate and transport of HECs throughout the receiving
25 environment shall be considered when characterizing results for this indicator. Uncertainty
26 levels should be reported in the LCA report and any EPDs or C-EPDs, preferably as a confidence
27 interval. The modeling uncertainty may be significant enough that the goal of the LCA study
28 cannot be achieved. In these cases, the goal and scope may need to be revised, or the
29 characterization of results must be at Node 1, which has less associated uncertainty.

30
31 The severity, spatial scale, reversibility, and persistence, of receiving environment contamination
32 associated with different emissions from different unit processes will vary broadly, depending
33 on factors such as the HEC emitted, scale of emission, timing of emission, duration of emission,
34 medium of emission, and regional setting. Associated midpoints and endpoints associated vary
35 for all of these reasons. Accordingly, site-specific assessment at this node is required. Secondary
36 data shall not be used in the characterization.

37
38 **5.3.4.2.3. Characterization of Emissions Levels.** At Node 1, indicator results assessed at this
39 node have no M-CF. Emissions contributing to a category indicator are assessed strictly as
40 emissions levels, and do not integrate fate and transport. Results at this node have low
41 environmental relevance, and should not be used as the basis for comparisons.

42 **5.3.5. Indicator Equation and Unit of Measure.** For results are shown in Equation 5.4, for cases
43 where the contaminants are not affecting an accumulated midpoint. Equation 5.5 is for the case
44 where contaminants affect an accumulated midpoint. Regardless of the node of characterization,
45 results are reported in units of mass equivalents of the reference substance.

46 **Equation 5.4. Indicator equation for HEC Exposure Risks, in the case where contaminants are not**
47 **affecting an accumulated midpoint.**

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$$HEC \text{ Exposure Risks} = \sum_i (Emissions_i \times PP-CF_i \times M-CF_i)$$

Where:

- Emissions are the emissions levels of a given HEC, reported in units of mass.
- PP-CF is the Potency Potential Characterization Factor for each HEC, representing its ecotoxicity relative to the reference contaminant.
- M-CF is the Midpoint Characterization Factor, which characterizes the fraction of the emission which contributes to the contamination of receiving environment(s) in exceedance of threshold.

1 Equation 5.5 Indicator equation for HEC Exposure Risks, in the case where contaminants are affecting
2 an accumulated midpoint.

$$HEC \text{ Contamination} = \sum_j \sum_i (Emissions_i \text{ in year } j \times PP-CF_i \times M-CF_i)$$

Where:

- Emissions are the emissions levels of a given HEC, reported in units of mass.
- *j* represents the total number of years in the LCA time horizon (for this accumulated midpoint)
- PP-CF is the Potency Potential Characterization Factor for each HEC, representing its ecotoxicity relative to the reference contaminant.
- M-CF is the Midpoint Characterization Factor, which characterizes the fraction of the emission which contributes to the contamination of the receiving environment.

3 **5.3.6. Additional Reporting Requirements.** In the LCA report and any EPDs or C-EPDs, the
4 midpoint of contaminated receiving environment in exceedance of threshold associated with a
5 category indicator shall be described.

6 The name of the category indicator used to assess results shall be clearly stated in the LCIA
7 profile. The name used shall clearly describe the modeling used, and not overstate the
8 environmental relevance of results.

9 **5.3.7. Addressing Additional Limitations in the Types, Accuracy and Availability of**
10 **Environmental Data.** The first step in characterization of results in this impact category is the
11 screening for determination of relevance of emissions, according to the requirements and
12 guidance provided in Section 5.3.2. In some anthropogenic systems, where unit process(es) in
13 the anthropogenic system are distributed in extensive global supply chains, lax regulations and
14 poor monitoring in certain regions might make it impossible to determine the relevance of
15 specific emissions sources to this impact category. If the screening cannot be conducted, then
16 determination of the relevance of this impact category is not possible; this could affect the ability
17 to achieve the goals of the LCA study. If the relevance of this impact category cannot be
18 determined, the goal and scope of the LCA study may need to be revised.

19 In certain cases, although the scale of emission from a unit process may be unknown, the nature
20 and region of an emission occurring in the anthropogenic system under study will be understood,
21 and there will be observational data which clearly shows that the emission contributes to the
22 active midpoint of contamination of a receiving environment in exceedance of threshold. In these
23 cases, the category indicator name shall be reported, with the midpoints and endpoints
24 described, although results cannot be assessed at any node.
25

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5.4. Freshwater Eutrophication

5.4.1. Impact Category. This impact category addresses freshwater eutrophication impacts. Freshwater eutrophication usually occurs when nutrients (biologically available nitrogen and phosphorus) are added beyond a receiving water body’s ability to process them. This leads to increases in primary productivity of algae, which in turn leads to multiple and complex changes to aquatic ecosystems, including blooms of microscopic and macroscopic algae, and increased turbidity in the water column. Eutrophication typically occurs as a result of indirect runoff from emissions to soil, or from direct emissions to water of eutrophying compounds. These effects are often called the “primary symptoms” of eutrophication, and are herein referred as such.

Increased decay as a result of increased algae formation will eventually deplete levels of dissolved oxygen, leading to hypoxia and anoxia; this depletion in oxygen levels leads to major disruptions to local ecosystems as organisms that require oxygen cannot survive. These effects are sometimes called the “secondary symptoms” of eutrophication, and are herein referred as such.

In rare cases, a second mechanism is also possible to deplete dissolved oxygen, whereby organic compounds in the water remove oxygen directly through enhanced aerobic microbial activity.

5.4.1.1. Definition of Threshold Exceedance for Eutrophication. A receiving water body may be in exceedance of threshold for primary and/or secondary symptoms. Threshold exceedance is determined separately for each type of symptom.

Receiving water bodies in exceedance of threshold for primary symptoms are those in which algae concentrations are above levels that the receiving water body can accept. These water bodies are experiencing negative effects to local ecosystems from primary symptoms, including reduction in benthic vegetation, and increased turbidity.

For a specific receiving water body, the conditions used to define the threshold for primary symptoms of eutrophication shall be quantitatively based, usually based upon measures of primary productivity in the water column, including but not limited to: mean productivity, chlorophyll-a concentrations, or algal biomass. Exceedance can also be based on concentrations of total phosphorus or nitrogen. The specific conditions of these measurements must be defined depending upon the characteristics of the affected receiving water body, considering the local climate, hydrology, ecosystem, and other considerations. The definition of the specific measures used to determine if a region is in exceedance of threshold for primary symptoms can be based upon local regulations.

For secondary symptoms of eutrophication, regions in exceedance of threshold include those in which the level of dissolved oxygen in the water column is below certain thresholds for hypoxia. Aerobic organisms in water bodies experiencing this exceedance are already seriously impacted.

For a specific receiving water body, the conditions used to define the threshold for secondary symptoms shall be based on measures of dissolved oxygen. The specific threshold values can vary based on local characteristics of the receiving water body; the exceedance of threshold values in Table 5. 5 can be used as a reference. Most regulatory frameworks, including the US Environmental Protection Agency, recognize 5 mg/L of dissolved oxygen content as a threshold for eutrophication.

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**Table 5. 5. Threshold characterization and exceedance of threshold values,
based upon the concentration of dissolved oxygen**

*Source: National Oceanic and Atmospheric Administration,
Effects of Nutrient Enrichment on the Nation's Estuaries. 2007.*

State	Dissolved Oxygen Content, mg/L	Threshold Condition
Anoxia	0	Exceedance of Threshold
Hypoxia	0-2	Exceedance of Threshold
Biological Stress	2-5	Exceedance of Threshold
	>5	Above Threshold

When determining the exceedance of threshold for primary or secondary symptoms in a specific water body, the temporal nature of eutrophication should be considered. Depending upon local conditions, exceedance of threshold could be episodic (i.e., occurring at infrequent intervals), periodic (i.e., occurring at frequent and predictable intervals, usually during the growing season), or persistent (i.e., occurring on a continuous basis). Understanding the temporal nature of the midpoint of exceedance of threshold can aid in characterization. The basis of determination of whether a receiving water body is in exceedance of threshold for either primary or secondary symptoms of eutrophication shall be described and justified in the LCA report.

5.4.2. Stressor-Effects Network. The stressor-effects network for this impact category depends upon the size, nature, location, timing, and duration, of an emission, as well as other considerations. The resulting scale, severity, timing, and duration of midpoints in the stressor effects network will vary for many reasons.

The stressor effects network for this impact category, shown in **Error! Reference source not found.**4 in Annex B, provides a general framework; however, for each receiving water body experiencing eutrophication which is affected by eutrophying emissions within the study scope (based upon the requirements of Section 5.4.2.1 and 5.4.2.2), a separate stressor-effects network should be modeled, describing the site-specific circumstances of stressors, midpoints, and endpoints, in the cause-effect relationship. This will greatly aid in the characterization of results, and will ensure that only relevant impacts are included.

The stressor effects network in **Error! Reference source not found.** includes both primary and secondary symptoms of eutrophication. However, in some cases, primary symptoms can occur and lead to endpoints, without the occurrence of secondary symptoms. In these cases, this stressor effects network will not apply, as the midpoint at Node 4 does not occur, and endpoints will be distinct. This illustrates the need to develop the stressor effects network for eutrophication separately each affected receiving water body included in the study scope.

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1 **5.4.2.1. Selection of Category Indicator(s).** For each receiving water body affected by
2 emissions of eutrophying substances which can be linked to unit process(es) in the
3 anthropogenic system under study, a distinct category indicator should be reported, provided a
4 distinct characterization model is established. A description and justification for the category
5 indicators which are reported shall be provided in the LCA report.

6 NOTE. This disaggregation is based upon the distinct nature of the stressor effects network of
7 eutrophication in distinct water bodies. The distinct nature of eutrophication in different locations is
8 affected by differences in the spatial extent and/or location of the receiving water body, type of receiving
9 water system (e.g., river or lake), severity of threshold exceedances, type of threshold exceedances (i.e.,
10 primary or secondary), and other considerations.

11
12 The characterization model which is used depends on the state of threshold exceedance in the
13 affected receiving water body. If the receiving water is in exceedance of threshold for secondary
14 symptoms, characterization shall be at Node 4, characterizing the fraction of an emission
15 transporting to areas in exceedance of threshold. If the receiving water is in exceedance of
16 threshold only for primary symptoms, characterization shall be at Node 3.

17
18 In some cases, characterization may be not be possible at these nodes, as a result of lack of
19 environmental data, or lack of data regarding the locations of unit process(es) in the
20 anthropogenic system. In these cases, characterization can be at Node 1, representing emissions
21 levels of eutrophying substances, provided that Eutrophication is determined to be a core impact
22 category according to the requirements of Section 5.4.2.2.

23
24 Characterization at Node 1 has low environmental relevance. This level of environmental
25 relevance shall be described in the LCA report and wherever results are reported.

26
27 In rare cases, emissions of both nutrients and organic chemicals directly contributing to oxygen
28 depletion may be affecting the same receiving water body in exceedance of threshold for
29 secondary eutrophication. In these cases, equivalencies can be established to aggregate nutrients
30 and oxygen depleting chemicals into a single category indicator, using PP-CFs. The basis of such
31 equivalencies must be described in the LCA report. If no equivalencies can be established using
32 credible research, then aggregation is not possible.

33
34 **5.4.2.2. Identifying Core Impact Categories and Category Indicator(s).** Due to the extensive
35 data collection and analysis required to characterize category indicators for this impact category,
36 it is essential to carefully screen the anthropogenic system under study to identify unit
37 process(es) which are contributing to eutrophication in receiving water bodies which are in
38 exceedance of threshold (Node 3 or 4 in the stressor-effects network). This screening should be
39 intended to minimize the amount of data collection required, by focusing the scope of the study
40 on emission(s) associated with a anthropogenic system which are linked to eutrophication in
41 regions in exceedance of threshold.

42
43 For a specific unit process, eutrophication should be included as a relevant core impact category,
44 if the following conditions are satisfied:

- 45 • Eutrophying emissions can be linked to activities at the unit process.

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- 1 • The eutrophying substances resulting from these emissions transport to a receiving water
2 body in exceedance of threshold for eutrophication (either primary or secondary
3 symptoms).

4 In the first iteration, the potential for eutrophication should be assessed at Node 1, using PP-CFs.
5 The unit process(es) which are the main contributors to the potential for eutrophication should
6 be identified, and their region determined. The nature of these unit process(es) should be
7 considered, to understand similar unit processes that have been known in the other cases to have
8 emissions which contribute measurably to eutrophication in local receiving water bodies. For
9 these unit process(es), the local regulatory setting and regional conditions should be understood.

10 The most significant type of unit process contributing to eutrophication is agriculture, especially
11 in certain regions, such as the Midwestern region of the United States. If agriculture in such a
12 region is found to be a significant contributor to final results for the potential for eutrophication,
13 then the specific emissions linked to activities at this unit process should be understood, and the
14 contribution to eutrophication in regions of exceedance of threshold determined.

15 Care should be taken when interpreting the outputs of LCI models, when using secondary
16 inventory databases. Emissions of eutrophying substances can vary broadly based upon the type
17 of unit process, regional practices, emission types, season of emission, and other considerations;
18 this means that secondary inventory data may have significant additional uncertainty.

19 This impact category should only be considered relevant if specific emission sources of
20 eutrophying substances are identified and linked to unit process(es) in the anthropogenic system
21 under study. These emissions sources must be described in the LCA report.

22 Sensitivity analysis can be used to help determine if eutrophying emissions can be linked to unit
23 process(es) in the anthropogenic system under study. If emissions of eutrophying substances are
24 reported in the LCI analysis, the significance of the emission should be determined by increasing
25 the scale of the functional unit. If, using the scaled up functional unit, the total emissions of
26 eutrophying substances across the entire anthropogenic system are negligible, this impact
27 category can be excluded as relevant.

28 **5.4.3. Classification.** Classification depends upon whether the affected receiving water body is
29 in exceedance of threshold for the primary or secondary symptoms of eutrophication, based on
30 the definitions in Section 5.4.1.1.

31 For category indicators characterizing contribution to eutrophication in a receiving water body
32 in exceedance of threshold for primary symptoms, emissions of all substances contributing to the
33 primary symptoms of eutrophication should be classified. This includes emissions of biologically-
34 available nitrogen and phosphorus compounds.

35 For category indicators characterizing contribution to eutrophication in a receiving water body
36 in exceedance of threshold for secondary symptoms, emissions of all substances contributing to
37 secondary symptoms of eutrophication should be classified. This includes emissions of
38 biologically-available nitrogen and phosphorus compounds, as well as organic chemicals
39 contributing directly to chemical and biological oxygen demand.

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1 In classification for category indicators at either node, the controlling nutrient must also be
2 identified for a given receiving water body. Nitrogen and phosphorus are the main nutrients
3 controlling algae growth, and initially, compounds of both nitrogen and phosphorus should be
4 considered. Only the controlling nutrient should be classified. If no specific data is available, it
5 can be assumed that phosphorus is the limiting nutrient.

6 NOTE. The relative importance of nitrogen and phosphorus varies between different water bodies, and
7 can even vary in the same water body over time. In most fresh water bodies, phosphorus is the limiting
8 nutrient. The limiting nutrient can be determined with N / P calculations.

9 **5.4.4. Characterization.**

10 **5.4.4.1. Potency Potential Characterization Factors.** PP-CFs are separately defined for
11 characterization of emissions of nutrients and oxygen depleting chemicals, based on the distinct
12 nature of these stressors and the midpoints they effect. For nutrients, the PP-CF characterizes the
13 potential contribution to algae formation, compared to the potential contribution to algae
14 formation from the limiting nutrient (either nitrogen or phosphorus). For oxygen depleting
15 chemicals, the PP-CF characterizes the potential contribution to depletion of oxygen.

16
17 In rare cases, emissions of both nutrients and oxygen depleting chemicals may be affecting the
18 same receiving water body in exceedance of threshold for secondary eutrophication. In these
19 cases, equivalencies must be established to aggregate nutrients and oxygen depleting chemicals
20 using PP-CFs. The basis of such equivalencies must be described in the LCA report. If no
21 equivalencies can be established using credible research, then aggregation is not possible, and
22 separate indicators must be reported (see Section 5.4.2.1).

23 **5.4.4.1.1. Characterization of Potential Contribution to Algae Formation.** For nutrients, the
24 PP-CF represents the potential contribution to algae formation of an emission, using the
25 Redfield ratio.⁴⁷ PP-CFs can be derived from peer-reviewed sources. PP-CFs based upon the
26 Redfield ratio are shown in Table 5. 6 for receiving environments with different limiting
27 nutrients.

28 **Table 5. 6. PP-CF values, characterizing the Redfield ratio in environments with different limiting**
29 **nutrients. Source: Table 6.1, Danish Guidelines^{48, 49}**

Substance	Formula	PP-CF (Nitrogen-Limited Environment)	PP-CF (Phosphorus Limited Environment)	PP-CF (Limiting Nutrient not determined)
		kg N. eq. / kg substance	kg P eq. / kg substance	kg NO ₃ - eq. / kg substance
Nitrogen Compounds				
Ammonia	NH ₃	0.82	0	3.64
Nitrate	NO ₃ ⁻	0.23	0	1.00
Nitrite	NO ₂ ⁻	0.30	0	1.35

⁴⁷ At this time, a method for computing PP-CFs for this indicator that is more accurate than use of the Redfield ratio has not been identified.

⁴⁸ M. Hauschild and Potting, J., 2003. Spatial differentiation in Life Cycle impact assessment - The EDIP2003 methodology. Institute for Product Development Technical University of Denmark.

⁴⁹ In situations where the limiting nutrient cannot be determined, the final column can be used.

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Cyanide	CN	0.54	0	2.38
Total Nitrogen	N	1.00	0	4.43
Phosphorus Compounds				
Phosphate	PO ₄ ³⁻	0	0.33	10.45
Pyrophosphate	P ₂ O ₇ ²⁻	0	0.35	11.41
Total Phosphorus	P	0	1.00	32.03

1 **5.4.4.1.2. Characterization of Potential Contribution to Depletion of Oxygen.** For oxygen
2 depleting chemicals, the PP-CF represents the potential contribution to depletion of oxygen
3 resulting from an emission. The PP-CF should be based on chemical oxygen demand (COD) or
4 biological oxygen demand (BOD) tests.

5 The COD test considers the amount of organic compounds in water, and is expressed in terms of
6 the mass of oxygen consumed per liter of solution (in units of mg/L). The BOD test measures the
7 amount of oxygen required for microorganisms to decompose organic matter, and is measured
8 in units of oxygen consumed per liter of solution (mg/L). Either basis is acceptable for the PP-CF
9 used in this indicator result.

10
11 Indicator results are reported in mass of oxygen demand, and so the PP-CF for this indicator is
12 computed as the mass of oxygen demand per mass of chemical emission. Either the COD or BOD
13 test can be used to evaluate this equivalency for specific chemicals.

14 **5.4.4.2. Midpoint Characterization Factors.** The M-CF represents the emissions transporting
15 into waters above exceedance of threshold, and so depends upon whether the characterization is
16 at Node 3 or 4 (representing contribution to symptoms of primary or secondary eutrophication,
17 respectively). The M-CF represents the fraction of emission of an eutrophying substance that is
18 transported into receiving waters in exceedance of threshold.

19
20 The M-CF is expressed on a scale of 0 to 1, with 1 representing 100 percent transport or
21 deposition in environments where thresholds are exceeded. In situations where emissions to soil,
22 water, and air are all occurring, M-CF values should be determined separately for each
23 compartment, to reflect differences in fate and transport.

24 **FOR EXAMPLE.** The M-CF for emissions to soil must account for the percent that runs off into waterways
25 and subsequently transports to the affected receiving water body.

26
27 Site-specific modeling techniques of fate and transport are required to assess the M-CF for
28 Eutrophication. When assessing M-CFs, published literature should be surveyed. Particularly in
29 regions subject to the regulation of emissions of eutrophying substances, government agencies
30 or other organizations may have established fate and transport models which can be used as the
31 basis of M-CFs. Whenever possible, this type of publicly available data should be retrieved and
32 used. The basis and data sources used to calculate M-CFs shall be described in the LCA report.

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1 **5.4.5. Indicator Equation and Unit of Measure.** If the category indicator is at Node 3 or 4,
2 results are calculated using Equation 5.7. For emissions of nutrients, the results are reported in
3 units of mass of nitrogen or phosphorus equivalent, depending on the limiting nutrient.

4 If the category indicator is at Node 4, and emissions are organic chemicals which directly
5 contribute to oxygen depletion, the results are reported in units of mass of chemical or biological
6 oxygen demand.

7 **Equation 5.7. Indicator equation for a single unit process for Eutrophication, characterized at Node 3 or 4.**

$$\text{Eutrophication} = \sum_n \sum_j \text{Emissions}_{n,j} \times \text{PP-CF}_{n,j} \times \text{M-CF}_{n,j}$$

Where:

- *n is the total number of eutrophying emissions linked to the unit process*
- *j represents soil, water, and air emissions, which may have different M-CF values for a specific eutrophying emission*
- *Emissions represent the eutrophying emissions linked to the unit process, in units of mass*
- *PP-CF represents the Redfield ratio of the emitted substance, when compared to nitrogen or phosphorus (depending on the limiting nutrient), or the potential contribution to oxygen depletion*
- *M-CF represents the fraction of the emission which transports into regions which are in exceedance of threshold for eutrophication*

8 **5.4.6. Additional Reporting Requirements.** In the LCA report and EPDs or C-EPDs, any receiving
9 water bodies considered in category indicators for eutrophication (meeting the requirements of
10 Sections 5.4.2.1 and 5.4.2.2) shall be described. In this description, the location of the water body,
11 type of symptom experienced, and severity of eutrophication in exceedance of threshold should
12 be included. The category indicator name shall describe the receiving water body which is
13 affected.

14 **5.4.7. Addressing Additional Limitations in Types, Accuracy, and Availability of**
15 **Environmental Data.** The most important environmental data regards the fate and transport of
16 eutrophying substances. In some cases, there may not be data available to establish M-CFs for a
17 category indicator, even in cases where specific emissions sources of eutrophying substances
18 have been identified in the anthropogenic system under study, and linked to the contribution to
19 exceedances of threshold of eutrophication in specific receiving water bodies, according to the
20 requirements of Section 5.4.2.1 and 5.4.2.2. In these cases, results can be reported at Node 1 for
21 unit process(es) which are known to contribute to eutrophication.

22 If data is not available to characterize eutrophication, or to determine if it is a relevant impact
23 category, it may not be possible to achieve the goals of the LCA study. In these cases, the goal and
24 scope may need to be revised.

25 **5.5. Terrestrial Eutrophication**

26
27

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1 This impact category is results from emissions to air of nutrient-containing compounds (i.e.,
2 compounds containing phosphorus and nitrogen), which can deposit into soils and lead to
3 nutrient concentrations in excess of the soil's ability to process them.

4
5 Compared to freshwater and marine eutrophication, terrestrial eutrophication is a rare
6 phenomenon. If found to be relevant an LCA study, the basis of its relevance shall be described in
7 the LCA report. This Standard does not specify requirements for accounting. If relevant, this
8 impact category shall be listed in final results, and results can be listed as "No data".
9

10 If an LCA study is developed providing results for this impact category, the methodology and data
11 sources used to generate results shall be transparently reported in the LCA report, and should be
12 subject to peer review. PCRs should be developed for situations where this impact category is
13 relevant, in order to provide metrics for calculation of results.
14

15
16 **6. Terrestrial/Freshwater Ecosystem Impacts (from Land Use and Conversion)**
17

18 This group of impact categories accounts for impacts caused by unit processes in the
19 anthropogenic system under study, that can lead to physical disturbances to biomes and losses
20 of key species, and resulting endpoints of effects to regional interconnected ecosystem(s). This
21 group accounts for changes in conditions of these ecological systems from "undisturbed"
22 conditions, unaffected by anthropogenic interference. The assessment must consider the past
23 history of changes, as well as the current degree of disturbance.
24

25 The group includes four impact categories:

- 26 • Terrestrial biome disturbance.
- 27 • Freshwater biome disturbance.
- 28 • Wetland biome disturbance.
- 29 • Key species habitat disturbance.
- 30

31
32 The first three impact categories account for physical changes in the conditions of biomes
33 resulting from activities at unit processes in the anthropogenic system. In these impact
34 categories, structural changes to specific biomes within the affected area are measured, and
35 compared to the "undisturbed" conditions, which are defined by biome. The types of biomes
36 which are disturbed can vary greatly, and additional impact categories of biome disturbance to
37 these three could be added if found to be relevant (e.g., coastal biome disturbance.)
38

39 Within each type of biome disturbed, reporting of multiple, distinct indicator results may be
40 required. For example, an industrial operation (e.g. forestry or mining) may result in disturbance
41 to several distinct watersheds, each of which have distinct endpoints and should be reported as
42 a separate category indicator results.
43

44 The fourth impact category characterizes the loss of key species, usually measured through an
45 assessment of habitat disturbance. This considers impacts leading to losses of key faunal or floral
46 species that are the most vulnerable, threatened, or endangered, or are extirpated. These impacts
47 are reported separately for each species affected. It is representative of effects to biodiversity in
48 the affected area.
49

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1 Disturbance to biomes and loss of key species can occur in two ways:
2

- 3 • Direct disturbance at the site of a physical disruption activity associated with a unit process.
4 Examples include forest clear cuts, excavation of open-pit mines, and construction of roads.
- 5 • Indirect disturbance, away from the site of a physical disruption activity associated with a
6 unit process. These disturbances result from cascading effects caused by physical disruptions
7 (e.g., increased sedimentation in watercourses downstream from a forestry operation), and
8 also from changes in the continuity of biomes and species communities such that the overall
9 ecology of the area changes over time.

10
11 The disturbance of biomes and loss of key species can impact ecosystem functions and
12 biodiversity. Ideally, these ecosystem impacts would be directly measured in terms of the
13 disturbance to the affected ecosystems. However, such comprehensive assessment is not
14 supported by ecological field assessment techniques. This group of indicators relies on measuring
15 the amount and degree of biome disturbance and key species losses rather than changes in
16 ecosystem health for the following reasons:
17

- 18 • While effects to specific biome and key species can be measured, little or no data are typically
19 available to measure the disturbance of overall ecosystem health.
- 20 • The disturbance of specific biomes and loss of key species reflects site-dependent situations
21 related to the specific location of unit processes, providing a spatial context for analysis.
- 22 • Different biomes and key species are not equivalent and may not be aggregated; evaluation
23 of different biomes may therefore highlight impacts that might be overlooked in an analysis
24 of overall ecosystem health.
25

26 The measurement of biome disturbance involves assessing the size, severity, and duration of
27 disturbance associated with activities at unit processes included in the study scope. The
28 measurement of key species loss typically involve assessing the size, severity, and duration, of
29 habitat disturbance. In some instances, key species loss can include measurements of regional
30 population reductions.
31

32 **6.1. Terrestrial Biome Disturbance**

33
34 **6.1.1. Impact Category.** This impact category addresses the disturbance to terrestrial biomes
35 caused by stressors associated with the anthropogenic system under study. In this Standard, a
36 terrestrial biome is defined as a biotic community in a specific terrestrial area, which is defined
37 by conditions such as prevailing vegetation structure, leaf types, plant spacing, vegetative
38 species composition, vegetative compositional structure, vegetative age structure, presence of
39 large living trees and snags (if relevant), presence of biomass (above and below ground), soil
40 conditions, connectivity, landscape heterogeneity, fragmentation, climate, and topography.⁵⁰
41

42 In this Standard, disturbance to a terrestrial biome is defined as the measurement of overall
43 ecological conditions in the classified area under study (see Section 6.1.3), when compared to
44 undisturbed conditions (i.e., unaffected by anthropogenic activities since the pre-industrial era)

⁵⁰ Lindenmayer, D.B., J.F. Franklin, and J. Fischer. General management principles and a checklist of strategies to guide forest biodiversity conservation. *Biological Conservation* 131 (2006) 433-445.

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1 and fully disturbed conditions (i.e., representing maximally disturbed areas) in an area within
2 the same biome type.

3
4 The degree, scale, and duration of terrestrial biome disturbance associated with different unit
5 processes will vary broadly, depending on factors such as the land use management practices,
6 regional biome, history of the landscape, duration of disturbance, and scale of disturbance.
7 Likewise, the midpoints and endpoints associated with this impact category vary for all of these
8 reasons. Accordingly, site-specific assessment of terrestrial biome disturbance associated with a
9 unit process is required. Secondary data shall not be used in the assessment of terrestrial biome
10 disturbance.

11
12 **6.1.2. Stressor-Effects Networks.** The stressor-effects network for terrestrial biome
13 disturbance is distinct for disturbances caused by each unit process. The stressors can vary
14 broadly, and the resulting midpoints and endpoints will vary for many reasons. Stressors can be
15 related to activities at unit process(es) considered in the anthropogenic system under study, as
16 well as to unit processes outside the scope of the LCA.

17
18 The stressor-effects network for terrestrial biome disturbance shown in Table 6.1 of Annex B
19 provides a general framework; however, separate stressor-effects networks should be modeled
20 and described for each separate terrestrial biome disturbance indicator in the study scope. The
21 specific stressor-effects network should describe the site-specific circumstances of stressors,
22 midpoints, and endpoints, in the cause-effect relationship in the classified area under study. This
23 should consider the past history of disturbance and land management in the classified area,
24 current management practices, and other considerations relevant to the environmental
25 mechanism. Additionally, the terrestrial biome affected shall be reported and described, as well
26 as a justification for its definition. This detailed modeling of the stressor-effects network will
27 greatly aid in the characterization of each category indicator.

28
29 The disturbance of a terrestrial biome is considered an endpoint in its own right; however, this
30 endpoint is linked to endpoints and midpoints of other stressor-effects networks, including those
31 related to disturbance to other biome types (e.g., freshwater and wetlands) and habitats (defined
32 in this Standard, Section 6.4, as an environment within which a specific key species normally
33 occurs). The endpoint of ecosystem disturbance is affected by midpoints and endpoints of all of
34 the affected biomes and habitats.

35
36 **6.1.2.1. Selection of Category Indicator(s).** Separate category indicators shall be reported
37 for disturbance to each distinct terrestrial biome affected by unit process(es) within the
38 anthropogenic system under study. This reflects the distinct nature of each terrestrial biome
39 experiencing disturbance. No aggregation of results is allowed between distinct category
40 indicators.

41
42 NOTE. In practice, at least one separate category indicator is reported for each unit process causing
43 terrestrial biome disturbance. Unit processes are usually located in different terrestrial biomes, and
44 stressors associated from different unit processes are usually different, as well. This leads to distinct
45 environmental mechanisms for disturbance.

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1 NOTE. In some cases, a unit process will be of a large enough spatial scale to affect multiple terrestrial
2 biomes.

3
4 The definition of a specific terrestrial biome should be based upon widely accepted frameworks,
5 which could include terrestrial ecoregions defined by the WWF,⁵¹ or Bailey's Ecoregions. In some
6 cases, the environmental mechanism associated with terrestrial biome disturbance for a given
7 unit process requires a definition that is different than reported in these frameworks. It is
8 acceptable to use a different definition for a terrestrial biome, provided a justification is reported
9 for the use of such definition, and the relationship to a commonly used framework is described.

10
11 **FOR EXAMPLE.** Within a broader biome type, distinct biomes with recognized high
12 conservation value could exist, and should be reported under separate category indicators.

13
14 Site-specific biome definitions will often be required in situations where the classified area under
15 study has very different disturbance levels and past history from other parts of the terrestrial
16 biome.

17
18 In some cases, only specific land cover types within a given terrestrial biome are affected by the
19 stressor(s) associated with a given unit process. In these cases, these specific land cover type(s)
20 should be described.

21
22 **FOR EXAMPLE.** For most forestry operations, harvests occur almost exclusively in forest stands
23 dominated by merchantable timber species. An operation in Northern California that produces
24 redwood and Douglas fir lumber, for example, will almost exclusively harvest from redwood,
25 Douglas fir, and tanoak forest types. These forest types should be noted in addition to the affected
26 terrestrial biome.

27
28 The indicator shall be at Node 2, if data is available, which characterizes terrestrial biome
29 disturbance by measuring alterations in ecological conditions in the terrestrial biome, when
30 compared to the undisturbed and fully disturbed reference areas.

31
32 In some instances, data will not be available to assess terrestrial biome disturbance. In these
33 situations, the affected biome(s) should be reported with results listed as "No data".

34
35 **6.1.2.2. Identifying Core Impact Categories and Category Indicators.** Due to the extensive
36 data collection and analysis required to characterize multiple category indicators for terrestrial
37 biome disturbance, it is essential to carefully screen the anthropogenic system under study to
38 identify those unit process(es) which are contributing to terrestrial biome disturbance. This
39 screening should be intended to minimize the amount of data collection required, by focusing
40 the scope of the study on stressor(s) associated with unit process(es) which are linked to
41 terrestrial biome disturbance.

42
43 Terrestrial biome disturbance can be ruled out as a relevant impact category if there are no unit
44 process(es) that contribute measurably to any environmental mechanism of terrestrial biome
45 disturbance. For a given unit process, the following guidance can be used to exclude terrestrial
46 biome disturbance as relevant:

⁵¹ WWF. Ecoregions. <http://worldwildlife.org/biomes>

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- 1
2 • If the anthropogenic system under study were to halt all activity, and all relevant
3 intermediate flows throughout the entire anthropogenic system were likewise
4 stopped, no measurable change in the stressors, midpoints, or endpoints of terrestrial
5 biome disturbance would be observed.

6 **FOR EXAMPLE.** The scope of a study is the assessment of an office wall, which includes components
7 made from primary (mined) aluminum. The total annual production volume of these wall systems requires
8 the production of 181 tons of bauxite ore from a mine located in Jamaica, which produces 4.5 million tons
9 of bauxite ore each year. Terrestrial biome disturbance can be excluded as relevant for this anthropogenic
10 system. Even if production of all office walls were to cease, the reduction in demand of 181 tons of bauxite
11 (0.004% of total production of the Jamaica mine) is well within market fluctuations, and will not affect any
12 stressors, midpoints, or endpoints for terrestrial biome disturbance at the mine.

13 **FOR EXAMPLE.** If the scope of a study is instead the assessment of the bauxite ore mine itself, terrestrial
14 biome disturbance will be a relevant core impact category. If all production of bauxite ore were to halt, the
15 stressors associated with this production (i.e., excavation, creation of tailings ponds) would be affected.

- 16
17 • If it can be demonstrated through observation that the activities at the unit process do not
18 contribute to a measurable alteration in ecological conditions of the affected terrestrial
19 biome.
20
21 • If the spatial extent of the unit process is small enough that it cannot result in a measurable
22 change to conditions in the terrestrial biome.
23

24 When conducting this screening, it is important to identify any types of unit process(es) in the
25 anthropogenic system which have been known in the past to contribute measurably to terrestrial
26 biome disturbance. This includes land-intensive production activities, such as forestry,
27 agriculture, and mining. Unit process(es) located in regions where terrestrial biome disturbance
28 is an issue of concern to regional government agencies, non-governmental organizations, or other
29 stakeholders, should also be identified. There will almost always be relevant impact categories
30 for terrestrial biome disturbance associated with these types of unit processes.
31

32 Whether this impact category is included as relevant to an anthropogenic system depends on the
33 goal and scope of the LCA study. When screening to determine if terrestrial biome disturbance is
34 a core impact category, the scale of the functional unit used shall be large enough to include
35 observed instances of terrestrial biome disturbance. The functional unit must not be set
36 arbitrarily low, which could rule out this impact category even in cases where terrestrial biome
37 disturbance is occurring and can be linked to a unit process. This screening will require expert
38 judgment, and may require sensitivity analysis.
39

40 An initial screening for the relevance of terrestrial biome disturbance as an impact category may
41 determine that the scale of the functional unit may need to be revised, or that goal and/or scope
42 may need to be revised in other ways. The exclusion of terrestrial biome disturbance as a core
43 impact category should be a key subject of the critical review phase.
44

45 Due to the complex data collection and analysis requirements, resources may be unavailable for
46 an assessment of terrestrial biome disturbance for a given LCA study. This will limit the

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1 comparability of results. If terrestrial biome disturbance cannot be characterized, the relevant
2 category indicators shall be listed in the LCIA profile. The affected biome types should be
3 described for each in the LCA report, and in EPDs and C-EPDs.

4 5 **6.1.3. Classification**

6
7 Once category indicator(s) are determined to be relevant for a given unit process in the
8 anthropogenic system under study, the spatial extent of the affected terrestrial area should be
9 measured. The classified area consists of all areas in which alterations in ecological conditions
10 (i.e., terrestrial biome disturbance) can be linked to stressor(s) associated with the unit process.

11
12 It is important that the classified area include lands that are directly affected by physical
13 disruption activities at a unit process as well as adjacent areas that are indirectly affected.
14 Generally, the portion of the classified area that is indirectly affected by an activity will be larger
15 than the portion that is directly affected. In the classification step, disturbance to the overall
16 landscape should be considered at a landscape scale, to capture all affected areas.

17
18 In many instances, three levels of affected areas can be identified to aid in classification. These
19 affected areas can generally be identified using publicly available satellite imagery through
20 software such as Google Earth. The classification of these areas can serve as a starting point in an
21 assessment of terrestrial biome disturbance:

- 22
- 23 1. *Areas affected by an activity through direct physical disruption.* This can include areas affected
24 by long-term land occupation, such as roads, dams, agriculture, or buildings. It can also
25 include areas affected by short-term land use, such as areas harvested during forestry, and
26 other land uses characterized by temporary activities.
 - 27
28 2. *The buffer zones surrounding areas affected directly by physical disruption.* These areas can be
29 indirectly affected by cascading effects, as well as changes in the continuity of the biome and
30 by edge effects. The area of buffer zone to be included depends on the activity leading to
31 terrestrial biome disturbance, characteristics of the regional biome, and other
32 considerations.
 - 33
34 3. *The landscape as a whole.* Even areas that not directly adjacent to those directly affected can
35 experience terrestrial biome disturbance, as a result of cascading effects and changes in the
36 overall continuity of the biome.

37
38 The classified area should be clearly defined geographically, with specific boundaries described.

39
40 Secondary LCI databases should not be used to classify the area affected by a given activity, for
41 several reasons:

- 42
- 43 • There is wide variation in the area that will be affected by a given activity, based upon the
44 specific region, land use management activity, and past history of disturbance. Even the use
45 of secondary LCI data characterizing a unit process in the same region as the one under study
46 could result in inaccurate and misleading results.
 - 47 • Secondary LCI databases do not account for the areas that are indirectly affected, although
48 these areas may dominate the area that must be classified.

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- 1 • Secondary LCI databases do not account for changes in classified areas over time. The area
2 affected by terrestrial biome disturbance is not static, and can change significantly even over
3 short time periods.
4

5 If there are no data available for classification, satellite imagery and other techniques can be
6 relied upon to create first-order estimates of the area that is classified. For forestry, calculations
7 of per-acre timber yields, if relevant to the region and tree species under study, can be used to
8 calculate the areas directly affected by timber harvests. However, approaches such as these
9 cannot generally be used to calculate the area that is indirectly affected.
10

11 ***FOR EXAMPLE.*** In Northern Brazil, roughly 200,000 hectares of forest must be cleared to produce
12 sufficient fuelwood for the charcoal required to produce 4 million metric tons of pig iron. This estimate is
13 based upon the aboveground carbon content of forests in this region. Thus, 200,000 hectares of clear-cut
14 forest are classified under the terrestrial biome disturbance indicator for every 4 million metric tons of pig
15 iron produced. However, this only accounts for areas of direct disturbance, not the indirectly disturbed
16 areas, which are generally a much larger area.

17
18 In some instances, a classification of all affected areas will not be possible, based on limitations
19 in available data. In these cases, the effect on final results of these omissions should be considered
20 and described in the underlying LCA report and any materials made publicly available. If the
21 effect on the results is significant, the goal and scope of the study may need to be revised.
22

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6.1.4. Characterization.

6.1.4.1. Potency Potential Characterization Factor. As noted in Section 6.1.2.1, no aggregation is allowed between separate category indicators representing different environmental mechanisms for terrestrial biome disturbance. For a single category indicator identified according to Section 6.1.3, the classified area has an PP-CF of 1.

6.1.4.2. Midpoint Characterization Factor. The Midpoint Characterization Factor is called the “Biome Disturbance Factor”, or BDF. The BDF characterizes the average disturbance level across the classified area. The disturbance level is calculated based on measurements of a relevant set of ecological conditions in the classified area, which are compared to measurements of these conditions in fully disturbed and undisturbed reference areas. The BDF thus assesses the ecological conditions in the classified area, on the full spectrum of possible conditions.

The BDF is a unitless number from 0 to 1, but is usually expressed as a percentage value.

Generally, there are several iterative steps in characterization of the BDF for the classified area:

- selection of the reference areas;
- selection of ecological conditions used to represent terrestrial biome disturbance; and
- characterization of disturbance.

Each of these steps requires careful consideration and expert judgment, and the specific methods used should be a key subject of any critical review. The methods used should be reviewed by a trained field ecologist.

6.1.4.2.1. Selection of Undisturbed Reference Area. The first step in characterization is the selection of the reference area. These areas are located within the same terrestrial biome as the classified area, and are as similar as possible to the classified area in terms of location, climate, topography, and land cover. The difference in the reference areas is the ecological conditions:

- *The undisturbed reference area.* This reference area has not been affected by significant anthropogenic activities for an extended period of time, sufficient for the ecosystem in the region to recover to characteristics of a mature ecosystem. Although it may have been affected by natural disturbance events which commonly occur in the terrestrial biome (e.g., wildfires), it has also been unaffected by rare, but catastrophic, natural events such as a tsunami, volcanic eruption or meteor strike.

In practice, there will rarely be reference areas available which can truly be said to be undisturbed according to these definitions. Even permanently occupied areas will experience regrowth of flora, albeit to a limited degree, and provide some ecosystem services to some species. Conversely, even primary-growth reference areas in extremely remote regions never affected by any resource extraction are still affected by anthropogenic climate change.

Therefore, the selection of the reference areas will always entail a careful consideration of possible alternatives that can best represent the idealized definitions of “undisturbed”. Most commonly, reference areas are defined by choosing representative areas close to the classified

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1 area. The undisturbed reference area should preferably be areas managed for conservation
2 purposes, including mature set-side areas, such as national parks.
3

4 The final results for terrestrial biome disturbance are very sensitive to the selection of the
5 reference area. Sensitivity analysis should be a key part of this selection process. If the study is
6 intended for use in an Environmental Product Declarations (EPD), the selection process of
7 reference areas should be specified in the relevant Product Category Rule (PCR). For LCA studies
8 not used for EPDs, a justification of the reference areas selected must be provided, along with a
9 clear description of its boundaries and the data sources used in its characterization.

10
11 **6.1.4.2.2. Selection of Measurements of Ecological Conditions to be Included.** Disturbance
12 is calculated through a quantitative comparison of measurements of ecological conditions in the
13 classified area and the reference area. The ecological conditions selected represent the key
14 conditions in the affected terrestrial biome. Selection of the ecological conditions to be included
15 in the comparison, and the data sources to be used, is a key part of the assessment, and requires
16 careful consideration and expert judgment. As much as possible, sensitivity analysis should be
17 used to assess the effect on final results of using different ecological conditions, measurements,
18 and data sources. The selection of these conditions should be based on a careful review of the
19 stressor-effects network and characteristics of the terrestrial biome.

20
21 In cases where measurements of ecological conditions are already available for the reference
22 area and the classified area, the following steps can be used to guide a selection of the ecological
23 conditions to be included in the study:
24

- 25 • The available data sources, and measurements of various conditions that could be included,
26 should be reviewed. A list of measurements available for the reference area and the study
27 area should be created, noting the data source, uncertainty (expressed as a confidence
28 interval, if possible), and date of each measurement.
- 29 • A set of measurements should be selected which assess ecological conditions relevant to the
30 regional biome. These measurements should be available for conditions in the classified area,
31 and the reference area.
- 32 • This set of measurements should be validated to determine their suitability for use. Some of
33 the factors considered in the validation include: the uncertainty in each measurement at each
34 site; the magnitude of difference in measurements between each site; whether there is a
35 statistically significant difference in conditions in the undisturbed reference area (if not, the
36 measurement may not be suitable for use); and the number of sample sites included in the
37 measurement.
- 38 • Based on this validation step, the list of measurements to be included in the calculation of
39 disturbance may need to be refined.
- 40 • The final list of measurements used in the calculation for biome disturbance should be
41 reported. Conditions in the reference area and area under study shall be included in the LCA
42 report.

43
44 In cases where measurements of ecological conditions are not available for two reference area,
45 or the classified area, measurements will have to be conducted to complete an assessment of
46 terrestrial biome disturbance. The process of selecting the measurements to include should
47 follow the same general steps of selection, validation, and iterative refinement. On-site sampling
48 may be required following a defined sampling plan. This sampling should consider the goal and
49 scope of the LCA study.

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1
2 In all cases, the geographical distribution of sampling points used to measure ecological
3 conditions should be understood to the extent possible. Measurements shall only be used if they
4 have sufficient geographical coverage across the classified area, for both directly and indirectly
5 affected areas. If stressor(s) are leading to extensive fragmentation of a terrestrial biome, the
6 disturbance levels in indirectly affected areas can be very high. In some cases, the disturbance
7 levels in such areas could be comparable to those in areas that are directly affected. PCRs should
8 be used in order to specify how measurement of ecological condition should be completed, laying
9 out detailed requirements.

10
11 In some instances, measurements of all desired ecological conditions may not be available. In
12 these cases, omitted measurements of ecological conditions must not result in significant changes
13 to the resulting terrestrial biome disturbance. Any expected biases and/or increases in
14 uncertainty should be described in the LCA report. If omitted measurements have a significant
15 effect on final indicator results, the goal and scope of the LCA may need to be revised.

16
17 In extreme cases, where no measurements are available, it may not be possible to evaluate
18 results. In these situations, the affected biome(s) should be reported with results listed as “No
19 data”.

20
21 In the underlying LCA report, the list of measurements of ecological conditions that were
22 included shall be described, as well as those that were excluded. For EPDs, the PCR should
23 describe the ecological conditions to be included.

24
25 **6.1.4.2.3. Characterization of Biome Disturbance Factor.** To assess the BDF, the average
26 disturbance level across the classified area is assessed. There are three steps:

- 27
28
- The measurements of each ecological condition are independently averaged across the
29 classified area and the undisturbed reference area.
 - These average measurements in are compiled into three independent sets of data,
30 representing conditions in each of the reference areas and the classified area. The uncertainty
31 (expressed as a confidence interval, if possible) associated with each average measurement
32 shall also be compiled.
 - The averaged measurements are normalized to units which are comparable between the fully
33 disturbed reference area, the undisturbed reference area, and the study area. Depending on
34 the type of measurement, this normalization is usually on a per-acre basis.
- 35
36
37

38 **FOR EXAMPLE.** The measurements of total aboveground biomass, measured in tons, is
39 normalized to tons of biomass per acre, each for the fully disturbed reference area, undisturbed
40 reference area, and area under study.

41
42 These steps will result in average values for each measurement of an ecological condition,
43 including values for the undisturbed reference area and the classified area. The uncertainty
44 associated with these measurements should be considered. If the uncertainty is very high, a
45 revision to the list of included measurements may be required.

46
47 Once all of the measurements of ecological conditions have been compiled, the average
48 conditions in the classified area are compared to the undisturbed reference area. The numerical
49 deviation of each measurement is assessed, which is a unitless number from 0 to 1 often

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1 expressed as a percentage, representing the condition of the classified area when compared to
2 the fully disturbed and undisturbed reference areas. A deviation value of “1” for a measurement
3 corresponds to the classified study area being fully disturbed in the ecological condition; a
4 deviation value of “0” corresponds to the undisturbed state.
5

6 For a given ecological condition, several approaches can be used to assess the deviation in
7 conditions in the classified area.
8

- 9 • *Linear comparison.* The deviation is calculated by taking the difference between the average
10 measurement value in the undisturbed reference area and the classified area. This difference
11 is then divided by the measured value in the undisturbed reference areas. The absolute value
12 of this ratio is taken, to assess a positive deviation value, from 0 to 1.
13

14 **FOR EXAMPLE.** At a forestry operation in Northern California, the measurement of the
15 number of trees greater than 29” in diameter was one of the ecological conditions included. In
16 the study area area, measurements showed that there were 7.8 trees per acre; in the undisturbed
17 reference area, 23 trees per acre. The difference between the undisturbed and reference area is
18 15.2 trees per acre, and between the undisturbed and fully disturbed reference areas, 21.7 trees
19 per acre. Dividing these two values, the deviation value for this condition is 0.66, or 66%.
20

- 21 • *Threshold approach.* A specific threshold is chosen for a given condition, based on the
22 condition in the undisturbed and/or fully disturbed reference area. If the condition in the
23 study area meets this threshold, the deviation is 0; if it does not meet this threshold, the
24 deviation is 1.
25
- 26 • *Other approaches.* Other approaches could be used to assess the deviation for each
27 measurement. These approaches could use a nonlinear equation to calculate the deviation, or
28 other functions.
29

30 Whichever approach is used, it must be described in the LCA report. For EPDs, the approach used
31 shall be based upon the PCR.
32

33 To assess the average disturbance level and the BDF, the average of all deviation measurements
34 is taken. The confidence interval can then be assessed, based upon the standard deviation of all
35 the deviation values.
36
37

38 **6.1.4.2.4. Considering Foregone Growth Over Time.** Indicator results shall consider the
39 foregone growth which would have occurred over the LCA time horizon, if the unit process halted
40 extraction activities. To assess results in the “no extraction” scenario and compare it to the
41 projected extraction activities considered in the scope, projections and extrapolations will have
42 to be made which will be disclosed in the LCA report. PCRs should specify the approach for
43 assessing foregone growth according to this approach.
44

45 **6.1.5. Indicator Equation and Unit of Measure.** For disturbance caused by a given unit
46 process in a single biome, the indicator result shall be calculated based upon the foregone
47 growth at a given point in time for each year in the LCA time horizon. PCRs should specify this
48 approach for the given extraction activity.
49

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6.1.6. Additional Reporting Requirements. The results in this impact category and the other impact categories in the Land Use Ecological Impacts group are unique, in that the indicator results do not vary with production levels on the site. Even if all stressors associated with a given unit process were to stop, and all production cease, in most situations, it would take decades for the disturbance levels to decline across the classified area. As a result, indicator results normalized to production volumes (i.e., intermediate flows) can be misleading.

Accordingly, in addition to the indicator result, the following information shall be included in EPDs and the LCA report, listed separately for each affected terrestrial biome.

Table 6.1. Required reporting parameters for Terrestrial Biome Disturbance.

Description	Value Reported
Terrestrial Biome Disturbed	<i>Name</i>
Current Biome Status	<i>To be reported as Critical, Endangered, Vulnerable, Relatively Stable, or Intact.^(A)</i>
Current Disturbance Level	<i>Percent Disturbance (Biome Disturbance Factor)</i>
Land Use	<i>Thousand acres to produce unit of production</i>
Current Disturbance Trend	<i>To be reported as Increasing Disturbance, Stable, Recovering, or Unknown. If data is available, the rate of change in disturbance level over the past 10 years shall be reported as a decadal average (i.e., +/-Percent Disturbance change per decade)</i>
Potential Maximum Biome Recovery Rate ^(B)	<i>Percent Disturbance per decade reduction</i>
Foregone Biome Recovery Each Decade	<i>Difference between Potential Maximum Recovery Rate and Measured Disturbance Trend</i>

- A. *Based on condition of the terrestrial ecoregion in which the biome is present, as reported in a framework such as the WWF Wildfinder database.*
- B. *This is the recovery rate in the scenario with no extraction occurring.*

The functional unit should be scaled such that the total extent of area of terrestrial biome affected by unit process(es) in the anthropogenic system is considered.

Meaningful comparisons for terrestrial biome disturbance can only be drawn if the scale of functional unit is reflective of the spatial scale of biome disturbance linked to activities associated with unit process(es) in the study scope, considering the entire classified area. When making comparisons, the current disturbance level, past history of disturbance at the sites under study, current practices, and anticipated trends in disturbance levels, must be considered. Expert judgment will be required to appropriately define the scope of the study such that comparisons are justified.

6.1.7. Addressing Limitations in the Types, Accuracy, and Availability of Environmental Data. Due to the complex data collection and analysis requirements, resources may be unavailable for an assessment of terrestrial biome disturbance for a given LCA study. This will limit the comparability of results.

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1 In cases where data are unavailable for an accurate characterization, the list of category
2 indicators representing distinct environmental mechanisms for terrestrial biome disturbance
3 (identified according to the requirements of Sections 6.1.2.1 and 6.1.2.2) shall be provided. This
4 list will provide a large amount of information in the LCIA profile regarding impacts to terrestrial
5 biomes.

6
7 If data are unavailable to identify affected terrestrial biomes, the comparability of results will be
8 limited significantly. The goal and scope of the study may need to be revised.

9
10 **6.2. Freshwater Biome Disturbance**

11
12 **6.2.1. Impact Category.** This impact category addresses the disturbance to freshwater biomes
13 associated with an anthropogenic system.

14
15 In this Standard, a freshwater biome is defined as an interconnected biotic community, including
16 watercourses, lakes, wetlands, and adjacent riparian areas, within specific watershed
17 boundaries, defined by: salinity; turbidity; water temperature; sedimentation rates; sediment
18 size distribution; flow rates; depths; channel contours; hydrology and hydraulics; water quality;
19 watershed area; tributary areas; stream lengths; presence of large woody debris; riparian canopy
20 cover; riparian zone vegetative species composition; climate; and geology.

21
22 In this Standard, disturbance to a freshwater biome is considered separately by watershed, and
23 is defined as the measurement of the overall ecological conditions in watercourses, lakes,
24 wetlands, and adjacent riparian areas, when compared to undisturbed conditions in that
25 watershed, and fully disturbed conditions in that watershed.

26
27 The level of freshwater biome disturbance associated with different unit processes will vary
28 widely, depending on factors such as land use management practices, regional biome, history of
29 the landscape, duration of disturbance, and scale of disturbance. Likewise, the midpoints and
30 endpoints associated with this impact category vary for all of these reasons. Accordingly, site-
31 specific assessment of freshwater biome disturbance associated with a unit process is required.
32 Secondary data shall not be used in the assessment of freshwater biome disturbance.

33
34 **6.2.2. Stressor-Effects Networks.** The stressor-effects network for freshwater biome
35 disturbance is distinct for disturbance caused by each unit process. The stressors affecting
36 freshwater biome disturbance vary widely, and the resulting midpoints and endpoints for
37 disturbance within each freshwater biome are distinct. Stressors can be related to activities at
38 unit process(es) considered in the anthropogenic system under study, but also can also be
39 associated with unit processes outside of the scope of the LCA.

40
41 The stressor-effects network for freshwater biome disturbance, shown in Table 6. 2 in Annex B,
42 provides a general framework. A separate stressor-effects network shall be modeled and
43 described for each separate indicator included for freshwater biome disturbance within the study
44 scope. The specific stressor-effects network should describe the site-specific circumstances of
45 stressors, midpoints, and endpoints in the environmental mechanism in the classified watershed.
46 This should consider the past history of disturbance and land management in the region, current
47 management practices, and other considerations relevant to the cause-effects chain. Additionally,
48 the characteristics of the affected freshwater biome should be reported and described, including

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1 but not limited to data such as the total watershed area, and length of watercourses, when data
2 are available. This detailed modeling of the stressor-effects network will greatly aid in the
3 characterization of each category indicator considered in this impact category.
4

5 The disturbance of a freshwater biome is considered an endpoint in its own right; however, this
6 endpoint is also linked to the endpoints and midpoints of other stressor-effects networks,
7 including those related to disturbance to other biome types (e.g., terrestrial and wetlands) and
8 habitats. The endpoint of ecosystem disturbance is affected by midpoints and endpoints of all of
9 the affected biomes and habitats.

10
11 **6.2.2.1. Selection of Category Indicator(s).** Separate category indicators shall be reported for
12 disturbance to each distinct freshwater biome within specific watershed boundaries affected by
13 unit process(es) within the anthropogenic system under study. This reflects the distinct nature
14 of each freshwater biome experiencing disturbance. No aggregation of results is allowed
15 between distinct category indicators.
16

17 Category indicators for freshwater biome disturbance are defined for each unit process in the
18 anthropogenic system that contributes measurably to any environmental mechanism of
19 freshwater biome disturbance. It is important that the selected category indicators include all
20 freshwater biomes that are directly affected by physical disruption activities at a unit process,
21 and adjacent areas that are indirectly affected. Generally, if this impact category is relevant for a
22 given unit process, there will be multiple environmental mechanisms relevant for freshwater
23 biome disturbance, and therefore, multiple category indicators.
24

25 The specific watershed boundaries used to delineate each freshwater biome can be defined on
26 multiple levels, depending on the hydrological characteristics of the region, and the level of data
27 available. These levels range from the regional scale, where watersheds are defined on the scale
28 of hundreds of millions of acres, to the sub-watershed level, where watersheds are defined on the
29 scale of thousands of acres.
30

31 NOTE. These multiple levels of watersheds are “nested”, such that multiple smaller watersheds exist
32 within the boundaries of a single larger watershed. The hierarchical definitions of each level of watershed
33 depend upon the watershed classification techniques used.
34

35 When classifying the category indicators for freshwater biome disturbance, the level of
36 watershed selected must be based upon the stressor-effects network of disturbance. This, in turn,
37 depends on the spatial scale of the stressors affecting the freshwater biome. Generally, the area
38 of the watershed used should roughly match the spatial extent of the stressor(s) leading to
39 freshwater biome disturbance.
40

41 **FOR EXAMPLE.** In even-aged forestry, harvests are performed by clear-cuts, which are generally
42 never more than one thousand acres in size, with harvests spread out in multiple parts of the
43 landscape. Disturbance to freshwater biomes occurs on a corresponding spatial scale. Category
44 indicators should therefore be based upon sub-watersheds, which generally match the scale of
45 thousands of acres.
46

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1 **FOR EXAMPLE.** In iron ore mining, the creation of open pit mines and tailings ponds will directly
2 and indirectly affect tens of thousands to hundreds of thousands of acres. The scale of the
3 watershed should match this spatial scale.
4

5 When identifying the specific watershed boundaries that delineate each freshwater biome
6 disturbed by a given unit process, spatial mapping will be required. In this mapping, the
7 watersheds in which stressors are present must be identified. The mapping of watershed
8 boundaries should use existing datasets, such as provided by government agencies or other
9 parties (e.g., the US Geological Survey's Watershed Boundary Dataset). Generally, such datasets
10 are freely available, though the data quality and level of watershed specificity will vary. The data
11 quality of the dataset used should be considered in the context of the goal and scope of the study.
12

13 **NOTE.** Advanced software tools such as ArcGIS can help this analysis, but are not required. Coarse
14 imagery provided by Google Earth or the US Geological Survey's National Atlas can be used.
15

16 In some cases, the available data will not be sufficiently granular to define a comprehensive set
17 of watershed boundaries at the spatial scale matching the stressor(s) associated with a given unit
18 process. In these cases, the best available data should be used to define watershed boundaries.
19 In addition, it shall be noted in the LCA report and EPDs and C-EPDs that the number of
20 watersheds affected is underreported. The effect on final results should be considered in the
21 context of the goal and scope of the LCA. Comparisons cannot be based on results where the
22 number of affected category indicators is significantly understated.
23

24 **FOR EXAMPLE.** In Northern Brazil, there is extensive deforestation associated with the
25 production of timber products and fuelwood for charcoal. This deforestation is occurring as a
26 result of clear-cuts which are at most one thousand acres in size, and the watershed assessment
27 should be consistent with this scale. However, the dataset available for this region only provides
28 comprehensive watershed boundaries defined at the regional scale, with watersheds between
29 2.5 million and 25 million acres in size. Results must report the affected watersheds to the best
30 extent available, and note that the number of affected watersheds is understated.
31

32 Disturbance shall be characterized at Node 2— i.e., characterizing freshwater biome disturbance
33 by measuring alterations in ecological conditions in the freshwater biome when compared to the
34 undisturbed and fully disturbed condition. This will require on-site monitoring across a
35 representative area of the biome, according to recognized techniques in field ecology.
36

37 In many cases, site data will be unavailable to assess freshwater biome disturbance. In these
38 cases, the affected freshwater biomes shall be reported with results listed as "No Data." The list
39 of category indicators representing distinct environmental mechanisms for freshwater biome
40 disturbance shall be reported in the LCIA profile.
41

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1 **6.2.2.2. Identifying Core Impact Categories and Category Indicators.** Due to the extensive
2 data collection and analysis required to characterize multiple category indicators for freshwater
3 biome disturbance, it is essential to carefully screen the anthropogenic system under study to
4 identify the unit process(es) contributing to freshwater biome disturbance. This screening is
5 intended to minimize the amount of data collection required by focusing the scope of the study
6 on stressor(s) associated with a anthropogenic system that are linked to freshwater biome
7 disturbance.
8

9 Freshwater biome disturbance can be ruled out as a relevant impact category if no unit
10 process(es) in the anthropogenic system contribute measurably to any environmental
11 mechanism of freshwater biome disturbance. For a given unit process, the following guidance can
12 be used to exclude freshwater biome disturbance as relevant:
13

- 14 • If the anthropogenic system under study were to halt all activity, and all relevant
15 intermediate flows throughout the entire anthropogenic system were likewise stopped, no
16 measurable change in the stressors, midpoints, or endpoints of freshwater biome disturbance
17 would be observed.
- 18 • If it can be demonstrated through observation that the activities at the unit process do not
19 contribute to a measurable alteration in ecological conditions of any freshwater biome.
- 20 • If the spatial extent of the unit process is small enough in relation to the affected watershed
21 that it cannot result in a measurable change to ecological conditions in any freshwater biome.
22

23 If freshwater biome disturbance is excluded for these or other reasons, the reasons should be
24 stated and justification provided for the exclusion in the LCA report.
25

26 When conducting this screening, it is important to identify any types of unit process(es) in the
27 anthropogenic system which have been known in the past to contribute measurably to
28 freshwater biome disturbance. This includes land-intensive production activities, such as
29 forestry and mining. Unit process(es) located in regions where freshwater biome disturbance is
30 an issue of concern to regional government agencies, non-governmental organizations, or other
31 stakeholders should also be identified. In some situations, regulatory agencies will set specific
32 requirements intended to protect the integrity of freshwater biomes within specific watersheds,
33 by controlling land use management activities associated with a unit process. These types of unit
34 processes should be considered for inclusion in the scope.
35

36 The scale of the functional unit used in the screening should be large enough to include observed
37 instances of freshwater biome disturbance. The functional unit shall not be set arbitrarily low,
38 which could rule out this impact category even in cases where freshwater biome disturbance is
39 occurring and can be linked to a unit process(es).
40

41 The geographical scope of the study should also be sufficient to identify where freshwater biome
42 disturbance is occurring and can be linked to a unit process(es) in the anthropogenic system. This
43 screening will take expert judgment, and may require sensitivity analysis.
44

45 An initial screening for the relevance of freshwater biome disturbance as an impact category may
46 determine that the scale of the functional unit may need to be revised, or that goal and/or scope
47 may need to be revised in other ways. Any exclusion of freshwater biome disturbance as a core
48 impact category should be a key subject of the critical review phase.
49

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1 Due to the complex data collection and analysis requirements, resources may be unavailable for
2 an assessment of freshwater biome disturbance for a given LCA study. This will limit the
3 comparability of results. If freshwater biome disturbance cannot be characterized, the relevant
4 category indicators shall be included in the LCIA profile. The areas of the affected watersheds for
5 each should be provided in the LCA report, and in EPDs and C-EPDs, if data are available. A
6 disclaimer shall be included explaining the limitations of comparability in EPDs and C-EPDs.

7
8 **6.2.3. Classification.** Once category indicator(s) are determined to be relevant for a given unit
9 process in the anthropogenic system under study, the affected watershed should be mapped
10 out, and its spatial extent measured. For each given category indicator, there is a distinct
11 classified watershed.

12
13 The data required for mapping and classification are readily available in hydrological datasets. It
14 can also be useful to understand additional characteristics of the freshwater biome, such as
15 length of watercourses, area of riparian zones, and number of lakes.

16
17 In some cases, a classification of all affected watersheds experiencing freshwater biome
18 disturbance will not be possible, based on limitations in available data. In these cases, the effect
19 on final results of these omissions should be considered and described in the underlying LCA
20 report and any materials made publicly available. If the effect on the results is significant, the goal
21 and scope of the study may need to be revised.

22
23 **6.2.4. Characterization**

24
25 **6.2.4.1. Potency Potential Characterization Factor.** As noted in Section 6.2.2.1, no
26 aggregation is allowed between separate category indicators representing different
27 environmental mechanisms for freshwater biome disturbance. The PP-CF is 1 for all indicators.

28
29 **6.2.4.2. Midpoint Characterization Factor.** The Midpoint Characterization Factor is called the
30 biome disturbance factor (BDF). The BDF characterizes the average disturbance level across a
31 freshwater biome, including all interconnected watercourses, lakes, wetlands, and adjacent
32 riparian areas, within specific watershed boundaries). The disturbance level is calculated based
33 on measurements for a relevant set of ecological conditions compared to fully disturbed and
34 undisturbed reference conditions. The BDF is a unitless number from 0 to 1, but is usually
35 expressed as a percentage value.

36
37 Generally, there are several iterative steps in characterization of freshwater biome disturbance:

- 38 • selection of measurements of ecological conditions used to represent freshwater biome
39 disturbance;
- 40 • definition of the undisturbed reference conditions (also known as properly functioning
41 conditions for the freshwater system); and
- 42 • characterization of the BDF.

43
44 All of these steps require careful consideration and expert judgment, and the specific methods
45 used should be a key subject of any critical review. The methods should be reviewed by a trained
46 field ecologist. The methodology should be defined in PCRs.

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1 In some cases, monitoring of conditions in freshwater biomes at a site may be required by local
2 regulatory agencies. Characterization should take advantage of monitoring that has already been
3 completed, to streamline data collection and improve the accuracy and consistency of results.
4

5 **6.2.4.2.1. Selection of Measurements of Ecological Conditions.** A set of measurements of
6 ecological conditions must be selected to use as the basis of characterization. Disturbance is
7 calculated through a quantitative comparison of measurements of ecological conditions in the
8 freshwater biome to undisturbed reference conditions or properly functioning conditions.
9

10 The ecological conditions selected represent the key conditions in the affected freshwater biome.
11 During the selection process, the stressor-effects network and freshwater biome definition
12 should be reviewed. In some cases, the required conditions of habitats for indicator species could
13 be used as a proxy. In cases where monitoring of ecological conditions in a freshwater biome is
14 already required by local regulatory agencies, the set of conditions used in that application can
15 be adapted to streamline data collection.
16

17 In the LCA report, the list of measurements of ecological conditions that were included shall be
18 described, as well as a list of measurements that were excluded. For EPDs and C-EPDs, the PCR
19 shall specify the ecological conditions to be included. If there are limitations in the available data,
20 this should be noted in the LCA report.
21

22 Once ecological conditions have been selected, measurements of each condition are to be
23 conducted across a representative set of monitoring locations in the classified watershed.
24 Measurements shall be used only if they have sufficient geographical coverage to accurately
25 represent conditions in the freshwater biome.
26

27 Wherever possible, measurements which have already been collected should be used to
28 streamline data collection. These measurements may have been conducted as a result of
29 mandatory regulatory requirements or for other purposes.
30

31 If primary data collection is required, a monitoring plan and sampling schedule must be
32 implemented, and measurements conducted according to clearly described procedures, all of
33 which must be described in the LCA report. This process should be in accordance with common
34 practices in field ecology.
35

36 **6.2.4.2.2. Definition of Undisturbed and Fully Disturbed Reference Conditions.** The
37 **undisturbed reference condition** is the condition in the freshwater biome if it significant
38 anthropogenic intervention had been absent for a sufficient period of time for the
39 characteristics of the watershed prior to human intervention can be re-established. It may have
40 been affected by natural disturbance events which commonly occur in the freshwater biome.
41 This can be based upon indicator species. PCRs shall specify the undisturbed reference
42 condition for freshwater biomes.
43

44 For each monitoring site in the freshwater biome, values for the undisturbed reference
45 conditions must be specified for each ecological condition, taking into account differences in sites
46 (e.g., channel width, gradient, depth).
47

48 Measurements of conditions in the freshwater biome at each site are compared against the
49 undisturbed reference conditions. These reference conditions can be defined based upon

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1 conditions in an adjacent watershed, or can be based upon minimum requirements for suitable
2 habitat for indicator species.

3
4 **FOR EXAMPLE.** At a site in Northern California, measurement of ecological conditions in a freshwater
5 biome includes the monitoring of the total piece frequency of large woody debris in streams. The
6 undisturbed condition for large woody debris is defined at each sampling site, and depends upon the
7 channel width at that site. At one site, the undisturbed condition is defined as at least 6.22 pieces per 100
8 feet, while at another site, the undisturbed condition is defined as at least 7.15 pieces per 100 feet.

9
10 **6.2.4.2.3. Characterization of Biome Disturbance Factor.** To assess the BDF, the deviation in
11 conditions for ecological variables at each monitoring site is assessed, compared to the
12 undisturbed conditions. A deviation value of “1” for a measurement corresponds to the site
13 being fully disturbed, while a deviation value of “0” corresponds to the undisturbed state. The
14 deviation can be expressed on a continuum from 0 to 1, for intermediate conditions.

15
16 This deviation can also be assessed using a threshold approach, where a condition at a site is
17 compared to a threshold defined based upon the undisturbed state. If the condition meets this
18 threshold, the deviation is 0; if it does not meet this threshold, the deviation is 1.

19
20 Other approaches can be used to assess the deviation for each measurement. Whichever
21 approach is used, it must be described in the LCA report. For EPDs, the approach used should be
22 based upon the PCR.

23
24 To assess the BDF, the deviation in all conditions at all sites is considered. It can be evaluated as
25 an average of these deviation measurements, or by another approach. Whichever approach is
26 used, it must be described in the LCA report. For EPDs, the approach used should be based upon
27 the PCR.

28
29 **6.2.5. Indicator Equation and Unit of Measure.** Due to the diverse nature of the
30 environmental mechanisms for this impact category and differences in available data, different
31 units of measure and indicator equations will be applicable in different contexts. The indicator
32 equation and unit of measure used should be reported and described in the LCA report. PCRs
33 shall specify the calculation methodology for this indicator.

34 **6.2.6. Additional Reporting Requirements.** The results in this impact category and the other
35 impact categories in the Land Use Ecological Impacts group are unique, in that the indicator
36 results do not vary with production levels on the site. Even if all stressors associated with a
37 given unit process were to stop, and all production cease, in most situations, it would take
38 decades for the disturbance levels to decline.

39
40 Regardless of whether the BDF is reported, the complete list of category indicators noting
41 watersheds affected by freshwater biome disturbance shall be included in the LCIA profile. LCA
42 reports and EPDs shall include a table which includes all information from the table below for
43 every affected or possibly affected freshwater biome.

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1 **Table 6.2. Required reporting parameters for the impact category of Freshwater Biome Disturbance, by freshwater**
 2 **biome. Results shall be reported for each freshwater biome in the LCA report and in EPDs.**

Description	Value Reported
Freshwater Biome Disturbed	<i>Name of Freshwater Biome or Watershed</i>
Area of Watershed	<i>Area in acres or hectares of watershed</i>
Current Freshwater Biome Disturbance Level	<i>Percent Disturbance (Freshwater Biome Disturbance Factor, FWBDF) or "Unknown"</i>
Disturbance Trend	<i>To be reported as "Increasing Disturbance", "Stable", "Recovering", or "Unknown" along with the documented change in FWBDF each decade</i>

3
4
5 **6.2.7. Addressing Limitations in the Types, Accuracy, and Availability of Environmental**

6 **Data.** Due to the complex data collection and analysis requirements, resources may be
 7 unavailable for an assessment of freshwater biome disturbance for a given LCA study. This will
 8 limit the comparability of results.
 9

10 In cases where data are unavailable for an accurate characterization, the list of category
 11 indicators representing distinct environmental mechanisms for freshwater biome disturbance
 12 (identified according to the requirements of Sections 6.2.2.1 and 6.2.2.2) shall be provided, with
 13 a conservative assumption that all are affected. This list will provide a large amount of
 14 information in the LCIA profile regarding impacts to freshwater biomes.
 15

16 If data are unavailable to identify affected freshwater biomes, the comparability of results will be
 17 limited significantly, and it may not be possible to achieve the goals of the study. The goal and
 18 scope of the study may need to be revised.
 19

20 **6.3. Wetland Biome Disturbance**

21
22 **6.3.1. Impact Category.** This impact category addresses the disturbance to wetland biomes
 23 that can be associated with a anthropogenic system.
 24

25 In this Standard, a wetland biome is defined as a biotic community in a specific wetland, defined
 26 by: salinity; turbidity; water quality; sedimentation rates; sediment size distribution; flow rates;
 27 depths; hydrology; vegetative cover; plant structure (if plants are present); bottom particle
 28 composition and structure; channel connectivity; channel complexity; tidal action (for saltwater
 29 wetlands); wave action (for saltwater wetlands); and climate.
 30

31 In this Standard, disturbance to a wetland biome is defined as the measurement of the overall
 32 ecological conditions in the wetland under study when compared to undisturbed conditions (i.e.,
 33 unaffected by anthropogenic activities) and fully disturbed conditions (i.e., maximally disturbed).
 34

35 The degree, scale, and duration of wetland biome disturbance associated with different unit
 36 processes will vary broadly, depending on factors such as the land use management practices,
 37 regional biome, history of the landscape, duration of disturbance, and scale of disturbance.
 38 Likewise, the midpoints and endpoints associated with this impact category vary widely.

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1 Accordingly, site-specific assessment of wetland biome disturbance associated with a unit
2 process is required. Secondary data shall not be used in the assessment of wetland biome
3 disturbance.

4
5 **6.3.2. Stressor-Effects Networks.** The stressor-effects network for wetland biome
6 disturbance is distinct for disturbance caused by each unit process. The stressors affecting
7 wetland biome disturbance vary widely, and the resulting midpoints and endpoints for
8 disturbance within each wetland biome are distinct. Stressors can be related to activities at unit
9 process(es) considered in the anthropogenic system under study, but also can also be
10 associated with unit processes outside of the scope of the LCA.

11
12 The stressor-effects network for wetland biome disturbance, shown in Table 6. 3 of Annex B,
13 provides a general framework. A separate stressor-effects network shall be modeled and
14 described for each separate indicator included for wetland biome disturbance within the study
15 scope. The specific stressor-effects network should describe the site-specific circumstances of
16 stressors, midpoints, and endpoints in the cause-effect relationship in the wetland under study.
17 This should consider the past history of disturbance and land management in the classified area,
18 current management practices, and other considerations relevant to the cause-effects chain.
19 Additionally, the characteristics of the affected wetland biome should be reported and described,
20 including, but not limited to, the watershed in which it is located, area of the affected wetland, the
21 wetland type (e.g., forested wetland, emergent wetland, saltwater estuary). This detailed
22 modeling of the stressor-effects network will greatly aid in the characterization of each category
23 indicator considered in this impact category.

24
25 The disturbance of a wetland biome is considered an endpoint in its own right; however, this
26 endpoint is linked to endpoints and midpoints of other stressor-effects networks, including those
27 related to disturbance to other biome types (e.g., terrestrial and freshwater) and habitats. The
28 endpoint of ecosystem disturbance is affected by midpoints and endpoints of all of the affected
29 biomes and habitats.

30
31 In most instances, wetland biome disturbance will be linked to freshwater biome disturbance.
32 These linkages should be understood. This will aid in the characterization of wetland biome
33 disturbance.

34
35 **6.3.2.1. Selection of Category Indicator(s).** Separate category indicators shall be reported for
36 disturbance to each distinct wetland biome affected by unit process(es) within the
37 anthropogenic system under study. This reflects the distinct nature of each wetland biome
38 experiencing disturbance. No aggregation of results is allowed between distinct category
39 indicators.

40
41 Category indicators for wetland biome disturbance are defined for each unit process in the
42 anthropogenic system that contributes measurably to any distinct environmental mechanism of
43 wetland biome disturbance. It is important that the selected category indicators include all
44 wetland biomes directly affected by physical disruption activities at a unit process, as well as
45 wetlands that are indirectly affected.

46
47 To identify affected wetlands, all freshwater biomes that could be affected by stressor(s) in the
48 anthropogenic system must first be identified and described, according to the requirements of
49 Section 6.2.2.1 and 6.2.2.2. Once specific watershed boundaries are defined for each freshwater

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1 biome, the wetlands within each can be identified. If wetland biome disturbance is occurring for
2 a specific wetland within these watershed boundaries, a category indicator should be described
3 if the environmental mechanism is distinct in nature from disturbance to the freshwater biome
4 in which the wetland is present.

5
6 There are a large number of wetlands of many different types, such as forested wetlands,
7 emergent wetlands, saltwater estuaries, and others. The wetland type should be considered
8 when a category indicator for wetland biome disturbance is being defined.

9
10 In some cases, multiple wetlands within a freshwater biome may be experiencing disturbance.
11 Separate category indicators shall be used for each wetland if the environmental mechanism of
12 wetland biome disturbance is distinct.

13
14 Disturbance should be characterized at Node 2, if data are available — i.e., characterizing wetland
15 biome disturbance by measuring alterations in ecological conditions in the biome, when
16 compared to the undisturbed and fully disturbed condition.

17
18 In cases where data are unavailable for characterization, the list of category indicators
19 representing distinct environmental mechanisms for wetland biome disturbance shall be
20 reported in the LCIA profile. If data is unavailable to define a comprehensive set of indicators for
21 wetland biome disturbance, see Section 6.3.7.

22
23 **6.3.2.2. Identifying Core Impact Categories and Category Indicators.** It is essential to
24 carefully screen the anthropogenic system under study to identify the unit process(es)
25 contributing to wetland biome disturbance. This screening is intended to minimize the amount
26 of data collection required, by focusing the scope of the study on stressor(s) associated with a
27 anthropogenic system linked to wetland biome disturbance. Wetland biome disturbance can be
28 ruled out as a relevant impact category if no unit process(es) in the anthropogenic system
29 contribute measurably to any environmental mechanism of wetland biome disturbance.

30
31 For a given unit process, the following guidance can be used to exclude wetland biome
32 disturbance as relevant:

- 33
- 34 • If the anthropogenic system under study were to halt all activity, and all relevant
35 intermediate flows throughout the entire anthropogenic system were likewise stopped, no
36 measurable change in the stressors, midpoints, or endpoints of wetland biome disturbance
37 would be observed.
 - 38 • If it can be demonstrated through observation that the activities at the unit process do not
39 contribute to a measurable alteration in ecological conditions in the wetland biome which is
40 affected.

41
42 If wetland biome disturbance is excluded for these or other reasons, the reasons should be stated
43 and justification provided for the exclusion in the LCA report.

44
45 The scale of the functional unit used in the screening should be large enough to include observed
46 instances of wetland biome disturbance; it must not be set arbitrarily low, which could rule out
47 this impact category even in cases where wetland biome disturbance is occurring and can be
48 linked to a unit process(es). An initial screening for the relevance of wetland biome disturbance
49 as an impact category may determine that the scale of the functional unit may need to be revised,

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1 or that goal and/or scope may need to be revised in other ways. The exclusion of wetland biome
2 disturbance as a core impact category should be a key subject of the critical review phase.
3

4 In some instances, identification of all affected wetland biomes experiencing disturbance will not
5 be possible, based on limitations in available data. In these cases, the effect on final results of
6 these omissions should be described in the LCA report. If the effect on the results is significant,
7 the goal and scope of the study may need to be revised.
8

9 Due to the complex data collection and analysis requirements, resources may be unavailable for
10 an assessment of wetland biome disturbance for a given LCA study. This will limit the
11 comparability of results, and may affect the ability to achieve the goals of the study. If wetland
12 biome disturbance cannot be characterized, the relevant category indicators shall be listed in the
13 LCIA profile. If data are unavailable to identify affected wetland biomes, see Section 6.3.7.
14

15 **6.3.3. Classification.** For a given category indicator, the affected wetland is classified. Once
16 category indicator(s) are determined to be relevant for a given unit process, it can be useful to
17 understand additional characteristics of each classified wetland, such as area. Mapping of the
18 affected wetland for each category indicator will aid in the characterization.
19

20 **6.3.4. Characterization**

21
22 **6.3.4.1. Potency Potential Characterization Factor.** As noted in Section 6.3.2.1, no
23 aggregation is allowed between separate category indicators representing different
24 environmental mechanisms for wetland biome disturbance. The PP-CF is 1 for all indicators.
25

26 **6.3.4.2. Midpoint Characterization Factor.** The Midpoint Characterization Factor is called the
27 biome disturbance factor (BDF). The BDF characterizes the average disturbance level across a
28 classified wetland, where the disturbance level is calculated based on measurements for a
29 relevant set of ecological conditions compared to undisturbed reference conditions (also known
30 as properly function conditions). The BDF is a unitless number from 0 to 1, but is usually
31 expressed as a percentage value.
32

33 Generally, the iterative steps in characterization at Node 2 for wetland biome disturbance will
34 include:

- 35 • selection of measurements of ecological conditions used to represent wetland biome
36 disturbance;
- 37 • definition of the undisturbed reference conditions; and
- 38 • characterization of the BDF.
39

40 Wherever possible, the same methods and data sources should be used in the characterization of
41 wetland biome disturbance as are used in the characterization of freshwater biome disturbance
42 (see Section 6.2.4). Since the stressor-effects network for wetland biome disturbance and
43 freshwater biome disturbance are almost always linked, there are very often stressors and/or
44 midpoints in common. Data sources from assessment of freshwater biome disturbance should be
45 used in the assessment of wetland biome disturbance when possible, dependent on the nature of
46 the environmental mechanism.
47

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1 The stressor-effects networks for different instances of wetland biome disturbance are extremely
 2 diverse, and the characterization model and nodal indicator used to calculate the BDF will vary
 3 considerably. In some cases, the main stressors could result in the complete elimination of
 4 wetlands (i.e., de-watering of wetlands); alternatively, stressors could be entirely indirect,
 5 involving increased sediment from land use practices in upstream watershed reaches far away
 6 from the wetland boundaries. Characterization of wetland biome disturbance is site-dependent,
 7 and will require the assistance of a trained field ecologist in most cases.

8
 9 The specific methods used shall be described in detail in the LCA report. The characterization of
 10 the BDF for wetland biome disturbance should be a key subject of any critical review.

11
 12 **6.3.5. Indicator Equation and Unit of Measure.** Due to the diverse nature of the
 13 environmental mechanisms for wetland biome disturbance, different units of measure and
 14 indicator equations will be applicable in different contexts. The indicator equation and unit of
 15 measure used should be reported and described in the LCA report.

16
 17 **6.3.6. Additional Reporting Requirements.** The results in this impact category and the other
 18 impact categories in the Land Use Ecological Impacts group are unique, in that the indicator
 19 results do not vary with production levels on the site. Even if all stressors associated with a
 20 given unit process were to stop, and all production cease, in most situations, it would take
 21 decades for the disturbance levels to decline.

22
 23 The functional unit should be scaled such that the total extent of area of wetland biome affected
 24 by unit process(es) in the anthropogenic system is included and reported in final results.

25
 26 Meaningful comparisons for wetland biome disturbance can only be drawn if the scale of
 27 functional unit is reflective of the spatial scale of biome disturbance linked to activities associated
 28 with unit process(es) in the study scope. LCA reports and EPDs shall include a table which
 29 includes all information from the table below for every affected wetland biome.

30 **Table 6.3. Required reporting parameters for the impact category of Wetland Biome Disturbance, by wetland biome.**
 31 **Results shall be reported for each wetland biome in the LCA report and in EPDs.**

Description	Value Reported
Wetland Biome Disturbed	<i>Name of Wetland Biome or Watershed</i>
Area of Wetland	<i>Area in acres or hectares of wetland</i>
Watershed of which Wetland is a Part	<i>Name</i>
Current Wetland Biome Disturbance Level	<i>Percent Disturbance (Wetland Biome Disturbance Factor, WBDF) or "Unknown"</i>
Disturbance Trend	<i>To be reported as "Increasing Disturbance", "Stable", "Recovering", or "Unknown" along with the documented change in WBDF each decade</i>

32
 33
 34 Regardless of the indicator results reported, the affected wetland included in each category
 35 indicator for wetland biome disturbance shall be reported in the LCA report. The category
 36 indicator name shall be descriptive of the affected wetland. If data are available, the type of
 37 wetland, size of wetland, and other relevant characteristics of the wetland biome should be
 38 disclosed in the LCA report, EPDs, and C-EPDs.

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6.3.7. Addressing Limitations in the Types, Accuracy, and Availability of Environmental Data. Due to the complex data collection and analysis requirements, resources may be unavailable for an assessment of wetland biome disturbance for a given LCA study. This will limit the comparability of results.

In cases where data are unavailable for an accurate characterization at any node, the list of category indicators representing distinct environmental mechanisms for wetland biome disturbance (identified according to the requirements of Sections 6.3.2.1 and 6.3.2.2) shall be provided.

If data are unavailable to identify affected wetland biomes, the comparability of results will be limited significantly, and it may not be possible to achieve the goals of the study. The goal and scope of the study may need to be revised.

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1
2 **6.4. Key Species Habitat Disturbance**

3
4 **6.4.1. Impact Category.** This impact category addresses the loss of key species that can be
5 associated with a unit process. Separate category indicators are evaluated for each
6 affected key species. In most cases, key species loss will be associated with the loss or
7 disturbance of suitable habitat. However, key species losses can occur even if there is no
8 measurable disturbance to biomes or habitats.

9 **FOR EXAMPLE.** A run-of-river hydropower system may not significantly alter surrounding habitats
10 but may impede migration of fish or injure individuals passing through turbines.

11
12 In this Standard, a key species is defined as a species of flora or fauna that meets one of the
13 following criteria in a given region:

- 14
- 15 • For the given region, the species has been listed as threatened, endangered, or extirpated on
16 an official government list. These lists can be: national in scale (i.e., the threatened and
17 endangered species lists maintained by the US Fish and Wildlife Service and National Oceanic
18 and Atmospheric Administration); or at a region, state, or local level (e.g., the Species of
19 Special Concern list maintained by the California Department of Fish and Wildlife).
 - 20
 - 21 • For the given region, the species is listed as vulnerable, threatened, endangered, or extirpated
22 on lists maintained by non-governmental stakeholders, such as ENGOs (i.e., the International
23 Union for the Conservation of Nature, or WWF).
 - 24
 - 25 • A species that has experienced a large reduction in populations in a given region, or has been
26 completely extirpated from a region, but is not included on any formal lists.
 - 27
 - 28 • Other species of concern based on their special significance or uniqueness within a given
29 region.
 - 30

31 Species that meet one of the above criteria may sometimes be excluded if they are not on national
32 governmental lists, have healthy populations throughout their historical range, and/or are
33 outside or at the edge of their historical range in the area for which they are listed. Critical review
34 by a trained field ecologist may be necessary to resolve the classification of a given species as
35 “key” if it is not officially recognized but is important to stakeholders. In all cases, the basis of the
36 selection of key species considered in the study scope shall be provided in the LCA report.

37
38 In rare cases, data will be sufficient to evaluate category indicator results through the loss of key
39 species populations in the classified study area. However, in most cases, category indicator
40 results will be based on the loss or disturbance of suitable habitat for the key species. This will
41 depend on the stressor-effects network of key species loss and the available data.

42
43 In this Standard, a habitat is defined as an environment where a species normally occurs. Habitats
44 may be defined independently for different life cycle stages of a single species. Stages of a life
45 cycle can include, but are not limited to: stages of maturity; breeding stages (e.g., nesting,
46 spawning); estivation or hibernation stages; roosting stages; or foraging stages. Many species will
47 require different habitat types for different life cycle stages.

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1
2 Habitat types can include terrestrial, freshwater, or wetland habitats, which will overlap with the
3 respective biomes on the site. Habitats can also include more specialized environments such as
4 old growth trees, ponds, or riparian zones. For a given unit process, there can be multiple habitat
5 types affected for a given species. Distinct category indicators are assessed if distinct types of
6 habitat are disturbed for key species. While generally there will be one category indicator
7 assessed for each key species experiencing habitat disturbance, there may be multiple category
8 indicators assessed for a single key species, if multiple habitat types for different life cycle stages
9 for a single species are impacted.

10
11 The habitat for a given life cycle stage of a given key species must be defined carefully based upon
12 the stressor-effects network of habitat disturbance. The definition of a habitat should draw upon
13 existing databases or published literature. Where relevant, it is useful to define habitats using the
14 same conditions as used to define biome types, using conditions defined in Section 6.1.1, 6.2.1,
15 and 6.3.1. However, while habitats may overlap with biomes, species very often require only
16 specific aspects within a given biome, or may require additional aspects. Different species will
17 require different habitats, which may overlap geographically.

18
19 The degree, scale, and duration, of key species loss associated with different unit processes will
20 vary broadly, depending on factors such as the land use management practices, regional biomes,
21 history of the landscape, duration of disturbance, and scale of disturbance. Likewise, the
22 midpoints and endpoints associated with this impact category vary for all of these reasons.
23 Accordingly, site-specific assessment of category indicators considered under key species loss is
24 required. Secondary data shall not be used in the assessment.

25
26 **6.4.2. Stressor Effects Networks.** The stressor-effects network for key species loss is distinct
27 for disturbance caused by each unit process. The stressors can vary broadly, and the resulting
28 midpoints and endpoints will vary for many reasons. Stressors can be related to activities at
29 unit process(es) considered in the anthropogenic system under study, but also can also be
30 associated with unit processes outside of the scope of the LCA.

31
32 The stressor-effects network for key species loss, shown in Table 6. 4 in Annex B, provides a
33 general framework. A separate stressor-effects network should be modeled and described for
34 each separate indicator included in key species loss in the study scope. The specific stressor-
35 effects network should describe the site-specific circumstances of stressors, midpoints, and
36 endpoints in the cause-effect relationship. This should consider the past history of disturbance
37 and land management in the classified area, current management practices, and other
38 considerations relevant to the cause-effects chain.

39
40 Separate category indicators will be defined for each affected key species. The affected species
41 shall be described in the LCA report and EPDs or C-EPDs, including its current population
42 conditions and its key life cycle stages, drawing on available databases and published research.
43 When the category indicator used is habitat disturbance or loss (as will usually be the case), the
44 affected habitat shall be reported and described in the LCA report and EPDs or C-EPDs. A
45 justification for its definition should be provided in the LCA report, along with a description of
46 habitat requirements. Detailed modeling of the stressor-effects network will greatly aid in the
47 characterization of each category indicator.
48

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2
3 The stressor-effects network in Table 6. 4 in Annex B includes the loss or disturbance of key
4 species habitat. However, in rare cases, key species loss may occur without a reduction in habitat.
5 In these cases, this stressor-effects network will not apply, as stressors occur directly at Node 3.
6 This illustrates the need to develop a unique stressor-effects network for each key species
7 affected by a given unit process.

8
9 The loss of key species is considered an endpoint in its own right; however, this endpoint is linked
10 to endpoints and midpoints of other stressor-effects networks, including those related to
11 disturbance to biomes and habitats for other species. The endpoint of ecosystem disturbance is
12 affected by midpoints and endpoints of all of the affected biomes and key species.

13
14 **6.4.2.1. Selection of Category Indicator(s).** Separate category indicators shall be reported for
15 each key species for which a reduction in species populations can be linked to unit process(es)
16 within the anthropogenic system under study. This reflects the distinct nature of the loss of
17 population for each key species. Generally, if this impact category is relevant for a given unit
18 process, there will be multiple environmental mechanisms relevant for key species loss, related
19 to different key species, and multiple corresponding category indicators. No aggregation of
20 results is allowed between distinct category indicators.

21
22 Additionally, if characterization is at the node of habitat disturbance or loss, multiple category
23 indicators should be assessed for a single key species if multiple habitat types for that species are
24 affected.

25
26 **FOR EXAMPLE.** In the state of Minnesota, iron ore mining has caused disturbance to both terrestrial
27 and freshwater biomes. One of the affected key species is Blanding's turtle. This species spends most of its
28 life in freshwater habitats, but ventures into terrestrial habitats to nest. For Blanding's turtle, two category
29 indicators should be assessed: disturbance to nesting habitat (in terrestrial settings) and freshwater
30 habitat.

31
32 It is important that the selected category indicators account for all key species experiencing
33 population reductions from physical disruption activities at a unit process, but also in adjacent
34 areas, which are indirectly affected.

35
36 The identification of affected key species requires mapping. Key species that have a historical
37 range overlapping any classified terrestrial, freshwater, or wetland biomes shall be considered
38 for inclusion. Additional key species may be classified if reductions in local species populations
39 can be linked to the activities at a unit process(es) in the anthropogenic system under study.

40
41 **NOTE.** The range map of key species can be found in official government databases (e.g., the US Fish
42 and Wildlife Service), or in databases provided by other organizations (e.g., WWF or International Union
43 for the Conservation of Nature).

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1 As a first step, a preliminary list of key species which could be affected should be generated using
2 publicly available databases and published literature. In some cases, regulatory agencies may
3 require monitoring of species at a given site, and any data generated from this monitoring can be
4 used to add to the list of key species.

5
6 In some cases, published data sources will not be sufficient to create a comprehensive list of key
7 species affected by a given unit process, and on-site sampling or more detailed research may be
8 required to establish a complete list. This type of detailed research should be considered in the
9 context of the goal and scope of the study. If the list of key species generated from available data
10 are inadequate, this limitation must be disclosed in the LCA report and described as a limitation
11 in results in EPDs and C-EPDs; the goal and scope may need to be revised.

12
13 Once a preliminary list of key species has been compiled, the species to be included will be
14 screened according to the requirements of Section 6.4.2.2. Species loss should preferentially be
15 characterized at Node 3 — i.e., characterizing the reduction in populations of key species in the
16 habitats affected by a unit process. This reduction shall be expressed as an absolute number (i.e.,
17 number of individuals lost), but should also be reported as a percentage value, considering the
18 previous population in the classified habitat, if such data are available.

19
20 However, in most cases, data are unavailable to characterize the reduction in key species
21 populations in a classified habitat; in such instances, characterization should be at Node 2, the
22 loss or disturbance of key species habitat. If data is unavailable for characterization, the number
23 of affected key species shall be included in the LCIA profile, as well as the information required
24 in Section 6.4.7.. If data are unavailable to create a comprehensive list of key species to be
25 included, see Section 6.4.7.

26
27 **6.4.2.2. Identifying Core Impact Categories and Category Indicators.** Due to the extensive
28 data collection and analysis required to characterize multiple category indicators for key species
29 loss, it is essential to carefully screen the anthropogenic system under study to the identify unit
30 process(es) contributing to this impact category. This screening is intended to minimize the
31 amount of data collection required, by focusing the scope of the study on stressor(s) associated
32 with unit process(es) linked to key species loss.

33
34 Key species loss can be ruled out as a relevant impact category if no unit process(es) in the
35 anthropogenic system contribute measurably to any environmental mechanism of key species
36 loss.

37
38 For a given unit process, a preliminary list of key species which could be affected should be
39 generated based on the requirements of Section 6.4.2.1. Once this preliminary list has been
40 generated, the following guidance can be used to exclude the unit process as contributing to
41 population reductions for a given key species:

- 42
43
- 44 • If detailed mapping finds that the historic range of the key species does not overlap with any
45 area that is affected by activities of the unit process, either directly or indirectly.
 - 46 • If the anthropogenic system under study were to halt all activity, and all relevant
47 intermediate flows throughout the entire anthropogenic system were likewise stopped, no
48 measurable change in the stressors, midpoints, or endpoints of key species loss would be
49 observed.

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- 1
2 • If it can be demonstrated through observation that the activities at the unit process do not
3 contribute to a measurable alteration in the habitat conditions or regional population of the
4 key species.

5
6 When conducting this screening, it is important to identify types of unit process(es) in the
7 anthropogenic system which have been known in the past to contribute measurably to key
8 species loss. This includes land-intensive production activities such as forestry, agriculture, and
9 mining.

10
11 Additionally, unit process(es) should be identified for consideration if they are located in regions
12 where key species loss is an issue of concern to regional government agencies, non-governmental
13 organizations, or other stakeholders. If a unit process is located in a region in which key species
14 loss is of high concern to any of these stakeholders, it shall be assessed for the presence of key
15 species affected. If a unit process is located in such a region, it is possible to identify a large
16 number of category indicators for key species loss.

17
18 **FOR EXAMPLE.** WWF has identified several “priority places” for conservation⁵² Among these places are
19 Borneo/Sumatra and the Amazon. If a plantation is located in these regions, it must be screened to
20 determine if key species loss is occurring as a result of on-site activities.

21
22 Whether this impact category is included as relevant to an anthropogenic system depends on the
23 goal and scope of the LCA study. The scale of the classified habitats considered in the screening
24 should be large enough to include observed instances of key species loss. This scale must not be
25 set arbitrarily low, which could rule out the impact category even in cases where key species loss
26 is occurring and can be linked to a unit process(es). This screening may require sensitivity
27 analysis.

28
29 An initial screening for the relevance of key species loss as an impact category may determine
30 that the scale of the habitat considered must be revised, or that goal and/or scope must be revised
31 in other ways. The exclusion of key species loss as a core impact category should be a subject of
32 the critical review phase.

33
34 **6.4.3. Classification.** Regardless of the nodal indicator used, classification first entails the
35 identification of the historic range of the key species in which populations have been affected by
36 activities associated with a given unit process. This is the classified range of a given species.

37
38 If characterization is of loss or disturbance to suitable habitat, the affected habitat(s) within the
39 classified range are defined, which depend upon the stressor-effects network. This includes all
40 historic habitat(s) that existed prior to the onset of significant anthropogenic activities at the site.
41 These are the classified habitat(s). The extent of classified habitat should be measured.

⁵² WWF, Priority Places. <http://worldwildlife.org/places>

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1 NOTE. Classified habitat(s) can be composed of many different components of different biomes at a site.
2 The extent of classified habitat will be measured in different ways depending on the habitat type.

3
4 FOR EXAMPLE. Classified terrestrial habitat is measured using units of acres. However, classified
5 habitat for a species that depends on trees of specific species or size could be measured in terms of the
6 number of trees.

7
8 If characterization is of loss of population (Node 3 in Table 6.5), the historic population in the
9 classified range prior to the onset of significant anthropogenic activities began at this location is
10 defined. This is the classified population.

11 NOTE. If historical observations are unavailable, the classified population could be evaluated by assessing
12 the number of individuals present in optimal habitat in undisturbed reference areas.

13
14 **6.4.4. Characterization**

15
16 **6.4.4.1. Potency Potential Characterization Factor.** No aggregation is allowed between key
17 species. The PP-CF is 1.

18
19 **6.4.4.2. Midpoint Characterization Factor.** Characterization of key species loss can be based
20 upon one of three different characterization models, at one of two different nodes in the
21 stressor-effects network:

- 22
23 1. For key species loss evaluated at the node of reduction in key species populations, the M-CF
24 is the Species Depletion Factor (SDF). The SDF is a unitless fraction from 0 to 1 (usually
25 expressed as a percentage), which characterizes the reduction in the number of individuals
26 in the classified population resulting from activities at a given unit process.
27
28 2. For key species loss evaluated as the disturbance of habitat, the M-CF is the Habitat
29 Disturbance Factor (HDF). The HDF is a unitless fraction from 0 to 1 (usually expressed as a
30 percentage), which is a measurement of the overall ecological conditions in the classified
31 habitat(s) when compared to undisturbed or optimal habitat conditions.
32
33 3. For key species loss evaluated as the loss of habitat, the M-CF is the Habitat Loss Factor (HLF).
34 The HLF is a unitless fraction from 0 to 1 (usually expressed as a percentage), which
35 expresses the reduction in the amount of habitat in the classified habitat(s) under study.
36

37 The choice of model and indicator used is based upon the environmental mechanism for key
38 species loss and the available data. While characterization of the SDF is preferred, data will be
39 available for this characterization only in rare cases, and typically the HDF or HLF will be
40 assessed.
41

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1 **6.4.4.2.1. Characterization of the Loss of Species Populations.** The SDF characterizes the
2 reduction in species population compared to the classified population. This is expressed as a
3 fraction from 0 to 1, but can also be expressed as a percentage.
4

5 **6.4.4.2.2. Characterization of the Loss or Disturbance of Species Habitat.** For
6 characterization at Node 2, whether the HDF or HLF is used depends on the stressor-effects
7 network:
8

- 9 • The HDF shall be used if a key species will still occur in a habitat that has been altered as the
10 result of activities at a given unit process.
- 11 • The HLF shall be used if a key species will not occur in a habitat that has been altered.

12 **FOR EXAMPLE.** At a site in Northern California, past forestry practices created many stressors that resulted
13 in freshwater biome disturbance, arising from increased sedimentation, changes in canopy cover in the
14 riparian zone, changes in water temperature, and other effects. Although alterations have affected habitat
15 for salmonid species, salmonids still occur in these freshwater habitats. Disturbance to suitable habitat
16 should be characterized using the HDF.

17 **FOR EXAMPLE.** At the same site in Northern California, past harvests have removed over 90% of trees
18 greater than 60" in diameter. The Marbled murrelet is a key species that nests only on large limbs of trees
19 of this size class. Since 90% of this nesting habitat has been removed, and will no longer be used by this
20 species, the HLF should be used for characterization.

21
22 There are several steps in characterizing the loss or disturbance of habitat:

- 23 • defining the undisturbed and fully disturbed habitat conditions;
- 24 • collecting measurements of conditions in the classified habitat(s); and
- 25 • characterizing the HLF or HDF.

26
27 **6.4.4.2.2.1. Defining the Undisturbed and Fully Disturbed Habitat Conditions.** If the HLF or
28 HDF are used for a given key species, the undisturbed habitat condition must first be defined.
29

30 The undisturbed habitat condition for a key species is optimal habitat (sometimes known as
31 "high-value" habitat) for the given life cycle stage for that species. The key species should show a
32 very strong preference for optimal habitat above all other habitat conditions. Optimal habitat
33 must be clearly defined in terms of measurements of a set of ecological conditions. An HDF or
34 HLF of 0 corresponds to optimal habitat conditions.

35 **FOR EXAMPLE.** In redwood forests of Northern California, high value nesting habitat for the Northern
36 spotted owl includes redwood and Douglas fir forests made up of trees over 24" inches in diameter, with
37 dense canopy cover (over 60%) in contiguous patches of at least 80 acres. These conditions define the
38 undisturbed, or optimal, habitat condition, for nesting habitat for the Northern spotted owl.
39

40 Optimal habitat conditions can be based upon observations of species in actual habitat, or based
41 upon measurements in reference areas close to the classified habitat(s) under study. Category
42 indicator results are sensitive to the definition of optimal habitat; the definition used should be
43 based upon peer-reviewed research. The definition of optimal habitat used should be a key
44 subject of the critical review phase, and should be reviewed by an ecology expert.

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1
2 **6.4.4.2.2.2. Conducting Measurements of Habitat Conditions.** When using either the HLF or
3 HDF, measurements of ecological conditions must be collected in the classified habitat(s). The
4 ecological conditions measured must be the same set used to define the undisturbed habitat
5 conditions.

6
7 Measurements must be collected from a sufficient number of sites to result in statistically
8 significant measurements that are representative of conditions in the classified habitat(s). These
9 measurements should be conducted using well-accepted practices in field ecology.

10
11 Databases and published literature containing data on conditions in the classified habitat(s)
12 should be collected first. If these data sources are inadequate for the purposes of characterization,
13 then on-site monitoring must be completed. This site monitoring should consider the goal and
14 scope of the LCA study. If adequate data are unavailable for the complete set of ecological
15 conditions, the effect on final results for a category indicator should be considered in the context
16 of the goal and scope of the LCA study. The goal and scope may need to be revised.

17
18 **6.4.4.2.2.3. Characterization of the Habitat Loss Factor.** If characterization is based upon the
19 loss of habitat using the HLF, then characterization considers the amount of useable habitat that
20 has been lost as a result of activities at a given unit process. The HLF is the fraction of the classified
21 habitat(s) which the species cannot use.

22
23 **6.4.4.2.2.4. Characterization of the Habitat Disturbance Factor.** To assess the HDF,
24 measurements of ecological conditions in the classified habitat(s) are compiled. The ecological
25 conditions measured are the same as those used to define the undisturbed and fully disturbed
26 habitat conditions.

27
28 Once these measurements of conditions in the classified habitat(s) have been compiled, the
29 numerical deviation is assessed for each condition. The deviation is a unitless number from 0 to
30 1 (often expressed as a percentage), which represents the condition of the classified habitat(s)
31 when compared to the undisturbed habitat conditions. A deviation value of “1” for a
32 measurement corresponds to the classified habitat(s) being unsuitable for use by this species in
33 this ecological condition. A deviation value of “0” corresponds to undisturbed (or optimal)
34 habitat. The HDF is the average of all deviation measurements.

35
36 Each deviation can be calculated using various approaches, such as a linear approach or threshold
37 approach, similar to the approaches described in Sections 6.1.4, 6.2.4, or 6.3.4. Whichever
38 approach is used, it must be described clearly in the LCA report.

39
40 **6.4.5. Indicator Equation and Unit of Measure.** Due to the diverse nature of the
41 environmental mechanisms for key species loss, differences in habitat characteristics, units of
42 measure, and indicator equations, different models will be applicable in different contexts. The
43 indicator equation and unit of measure used should be reported and described in the LCA
44 report.

45 **6.4.6. Additional Reporting Requirements.** The results in this and the other impact categories in
46 the Land Use Ecological Impacts group are unique, in that the indicator results do not vary with
47 production levels on the site. Even if all stressors associated with a given unit process were to stop,

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1 and all production cease, in most situations, it would take decades for habitats or populations to
2 recover across the classified range, if recovery is indeed possible.

3
4 Meaningful comparisons for key species loss can only be drawn if the scale of functional unit is
5 reflective of the spatial scale of habitat disturbance or population loss linked to activities
6 associated with unit process(es) in the study scope, considering the entire classified range. When
7 making comparisons, the current disturbance or population level must be considered in the
8 context of historical disturbances at the sites under study, and anticipated future trends. Expert
9 judgment will be required to appropriately define the scope of the study such that comparisons
10 are justified.

11
12 LCA reports and EPDs shall include a table which includes all information from the tabelow for
13 every affected key species.

14 **Table 6.4. Required reporting parameters for the impact category of Key Species Losses. A table shall be provided in the**
15 **LCA report and in EPDs which includes this information for all threatened species.**

Description	Value Reported
Species Name	<i>Common Name</i> <i>Latin Name</i>
Threatened Category	<i>Threatened, Endangered, etc.*</i>
Total Population Reduction from Historic	<i>Percent Reduction, or Unknown**</i>
Total Population Trend	<i>Increasing, Stable, Decreasing, Unknown**</i>

16 **Shall include a reference of the list used to determine this threatened category (e.g., IUCN Red List).*

17 ***Shall include a reference to the source of this information.*

18
19 **6.4.7. Addressing Limitations in the Types, Accuracy, and Availability of Environmental**
20 **Data.** Due to the complex data collection and analysis requirements, resources may be
21 unavailable for an assessment of key species loss for a given LCA study. This will limit the
22 comparability of results.

23
24 In cases where data are unavailable for an accurate characterization at any node, the list of
25 category indicators representing distinct environmental mechanisms for key species loss
26 (identified according to the requirements of Sections 6.4.2.1 and 6.4.2.2) shall be provided.

27
28 If data are unavailable to identify affected key species, the comparability of results will be limited
29 significantly, and it may not be possible to achieve the goals of the study. The goal and scope of
30 the study may need to be revised.

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7. Human Health Impacts (from Chronic Exposure to Hazardous Chemicals)

The impact categories in this group address endpoints to human health. There are six impact categories in this group:

- Ground Level Ozone (GLO) Exposure Risks.
- PM2.5 Exposure Risks.
- Hazardous Ambient Air Contaminant Exposure Risks.
- Hazardous Indoor Air Contaminant Exposure Risks.
- Hazardous Food or Water Contaminant Exposure Risks.
- Dermal Contaminant Exposure Risks.

These impact categories characterize hazardous chemical releases that present health risks to humans from exposure, and include chemicals that are cancer-causing, and those that can lead to acute and non-cancerous chronic health effects.

Each of these impact categories represents a distinct environmental mechanism, based on the route and extent of exposure of humans of various hazardous substances. Aggregation of these emissions into just one or two category indicators is not allowed. Each environmental mechanism for which a distinct characterization model is available is modeled as separate category indicator.

The first two impact categories (GLO Exposure Risks, and PM2.5 Exposure Risks), will be relevant to almost all anthropogenic systems. These impact categories address exposure to ozone and particulate matter, which are the two most harmful components of urban smog. Urban smog is prevalent in almost all industrialized regions in the world.

The last four impact categories address the three most common routes of exposure to humans resulting from emissions of hazardous substances. For the purposes of this Standard, to be defined as “hazardous”, a substance must satisfy two conditions: (1) there must be a documented route of exposure to humans, which leads to a measurable risk of exposure; and (2) exposures have been observed to result in toxic effects in humans.⁵³ Although a chemical may be inherently toxic if a human is exposed, if there is no route of exposure, no toxic endpoints can result. For the purposes of this Standard, chemicals are only considered hazardous if there is a route of exposure and inherent toxicity has been documented.

7.1. Ground Level Ozone (GLO) Exposure Risks

7.1.1. Impact Category. The impact category for ground level ozone (GLO) exposure risks considers human health impacts which could result from exposure to ground level ozone. Impacts to vegetation are not addressed.

⁵³ Hazardous chemicals may include those listed under: the US EPA, under the provisions of SARA Title III Section 313, Toxic Release Inventory (TRI), Clean Air Act (CAA) Section 112(r) substances; the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA); the International Agency for Research on Cancer (IARC) Monographs on the Evaluation of Carcinogenic Risks to Humans; and chemicals of concern in other countries where studies are conducted. These are listed, for instance, in US EPA, Office of Solid waste and Emergency Response’s “List of Lists: Consolidated List of Chemicals Subject to the Emergency Planning and Community Right-To-Know Act (EPCRA) and Section 112(r) of the Clean Air Act,” EPA 550-B-01-003, October 2001.

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1 It is important to recognize that industrial sources of GLO only emit precursors and do not
2 actually emit GLO directly. The major types of precursors are nitrogen oxides (NO_x) and non-
3 methane volatile organic compounds (NMVOCs), which react to form GLO under certain
4 atmospheric conditions, usually only in certain times of the year.
5

6 Millions of people live in regions with elevated concentrations of GLO, and exposures can lead to
7 a wide variety of illnesses and lifelong disabilities. Human health impacts are widely recognized
8 to occur above certain ambient concentrations of GLO; as a result, in many countries, emissions
9 are tightly controlled in “non-attainment areas”, where these health thresholds are exceeded
10 regularly.

11 ***For example.*** The US Environmental Protection Agency has set National Ambient Air Quality Standards
12 (NAAQS) to protect human health for several air pollutants, including ozone. The current NAAQS standard
13 for ozone is 75 parts per billion (ppb), determined over a rolling average of an 8-hour period. Under the
14 NAAQS, areas in non-attainment are those in which the 3-year average of the fourth highest 8-hour average
15 maximum ozone concentrations is over 75 ppb. These NAAQS threshold levels are used assess air quality
16 with respect to human health and to seek mitigation and controls from major sources of various precursors
17 in a given region.
18

19 The preponderance of evidence shows that the 75 ppb threshold used in the NAAQS does not
20 address chronic health effects in sensitive human populations, which occur at lower
21 concentrations of GLO. The World Health Organization (WHO) has defined an average
22 concentration of 60 ppb of ozone over an 8-hour period as a health threshold relevant to sensitive
23 populations.

24 NOTE. The 60 ppb health threshold is the regulatory guideline imposed in the European Union.
25

26 Based on the health threshold defined by the WHO, this impact category accounts for emissions
27 of ozone precursors that contribute to ozone which transports into regions in which
28 concentrations of GLO exceed the 60 ppb 8-hour health threshold at any point during the year.

29 NOTE. GLO is also a source of tropospheric ozone, a climate forcing substance, representing a serial impact
30 mechanism accounted for under a separate group of impact categories (see Section 4 of Annex A).
31

32 **7.1.1.1. Definition of Threshold Exceedance for GLO Exposure Risks.** The World Health
33 Organization (WHO) has defined an average concentration of 60 ppb of ozone over an 8-hour
34 period as a health threshold relevant to sensitive populations. The indicator used in this
35 Standard is based upon this health threshold. Regions where the 8-hr average ozone
36 concentration exceeds 60 ppb at any time of year are considered to be in exceedance of the
37 threshold.
38

39 **7.1.2. Stressor-Effects Network.** The stressor effects network for GLO Exposure Risks is shown in
40 Table 7. 1 in Annex B. The spatial extent, severity, and level of threshold exceedance, of the
41 midpoints in the stressor-effects network will vary significantly based upon the region of
42 emission, season of emission, emission type, and other considerations. Site-specific assessment
43 of category indicators in this impact category are required, in order to reflect this regional
44 variability. The use of representative data in characterization can help to guide characterization

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1 during the iterative process, but could lead to significant uncertainties which may compromise
2 the ability to achieve the goals of the LCA study.

3 **7.1.2.1. Selection of Category Indicator.** For this impact category, one category indicator is
4 assessed, for GLO Exposure Risks. The category indicator shall be at Node 4, representing the
5 contribution to increases in regional GLO concentrations in regions where health thresholds are
6 exceeded, leading to chronic risks of exposure to humans over threshold.

7 In some cases, data may be unavailable to assess results at Node 4. This may be due to a lack of
8 data regarding the locations of unit process(es) in the anthropogenic system, lack of data for
9 dispersion modeling, or lack of population density maps. Due to the high variability in the
10 stressor-effects network for this impact category, results at Node 1 have very low environmental
11 relevance, and could be misleading. If results cannot be assessed at either Node 4, results for GLO
12 Exposure Risks should be reported as “No data.”

13 NOTE. Results at Node 1 account only for potential photochemical ozone formation, omitting differences
14 in total exposed regional populations, and exposure to different levels of GLO concentrations over
15 threshold. Once the differences in the severity and population densities are included in the category
16 indicator calculation, differences in indicator results for similar emissions levels can be significant. For GLO
17 Exposure Risks, comparisons based upon Node 1 results would be misleading.

18 **7.1.2.2. Identifying Core Impact Categories and Category Indicator(s).** Based on the WHO
19 health threshold, GLO Exposure Risks will be relevant for any unit process(es) in the
20 anthropogenic system which emit ozone precursors that contribute to the elevation of ozone
21 concentrations in regions in which concentrations of GLO exceed the 60 ppb 8-hour health
22 threshold at any point during the year. GLO Exposure Risks is only relevant for emission
23 precursors leading to ozone formation which disperses into regions in exceedance of the health
24 threshold.

25 To determine for which unit process(es) GLO Exposure Risks is relevant, the region(s) included
26 in the scope of the LCA study must first be mapped, identifying areas in exceedance of the 60 ppb
27 8-hour health threshold. This mapping is based on rolling 8-hour average ozone concentrations,
28 using ambient monitored ozone data that is interpolated and processed. Areas in exceedance of
29 the threshold should be identified; the only unit process(es) included are those which emit ozone
30 precursors, which form GLO, which in turn transports to any region in exceedance of threshold.

31
32 When considering the anthropogenic system as a whole, GLO Exposure Risks will be a relevant
33 impact category in almost all cases, and this impact category can initially be assumed to relevant
34 for a given LCA study. This is due to the nearly ubiquitous emissions of ozone precursors from
35 combustion, arising from energy generation and from other sources, and the elevated
36 concentrations of ozone in most regions where extensive industrial activity occurs. Only if a
37 anthropogenic system has a scope limited to unit processes in remote regions, away from
38 industrial activities, could GLO Exposure Risks not be relevant.

39 **7.1.3. Classification.** Air emissions leading to the formation of ground level ozone are
40 classified. This depends upon whether the receiving environment into which ozone precursors
41 transport is NO_x-limited, or VOC-limited.

42 Whenever the ambient concentration (measured in parts per million, or ppm) of VOCs is more
43 than approximately 8 times that of NO_x, the reaction that creates ozone is limited by the amount
44 of NO_x in the air (NO_x-limited). Similarly, when the concentration of VOCs is less than

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1 approximately 8 times that of NO_x, the reaction is said to be VOC-limited. Only the limiting
2 precursor shall be classified.

3
4 In practice, most receiving environments are NO_x-limited. Unless determined otherwise with
5 specific ambient monitoring data, it shall be assumed that local receiving environments are NO_x-
6 limited, with little or no incremental contribution to ozone formation occurring from emissions
7 of VOCs. NO_x are the only substances which contribute to ozone formation in these conditions,
8 and are the only emissions included in results. This includes emissions to air of nitrogen dioxide,
9 nitrogen oxide, and unspecified nitrogen oxides.

10
11 The basis of determination for whether receiving environment(s) considered in the study scope
12 are NO_x-limited, or VOC-limited, should be described in the LCA report.

13 **7.1.4. Characterization.**

14 **7.1.4.1. Potency Potential Characterization Factors.** The PP-CF for this indicator
15 represents the chemical transformation of the ozone precursor emissions into ground level
16 ozone. The conversion rates are dependent upon meteorological conditions and the background
17 concentrations of both VOCs and NO_x.

18 For NO_x-limited receiving environments, the ratios of conversion from NO_x to ozone can range
19 significantly — for instance, from 0.2 to 1.3 kilograms ozone per kilogram of NO_x released. If data
20 is unavailable regarding site-specific conversion rates, a default PP-CF value of 1 for NO_x can be
21 used, which is the equivalent of one kilogram of ozone formed per kilogram of NO_x emitted. While
22 the specific conversion rate may vary, a PP-CF of 1.0 ton O₃/ ton emitted NO_x shall be used as a
23 default, based on global average conversion rates of NO_x to ozone.⁵⁴

24 NOTE. The confidence interval for this PP-CF may be roughly ±40% to ±50%, depending on the region and
25 time of year of emission.⁵⁵ The effect on final results of using an PP-CF with this level of uncertainty should
26 be considered; if the effect is significant, it may be necessary to model PP-CFs using site-specific
27 atmospheric chemistry models, to accurately determine the conversion rate of ozone precursors into GLO.

28
29 For VOC-limited receiving environments, the PP-CF for relevant VOCs should be based upon
30 measures such as the Maximum Incremental Reactivity.

31
32 **7.1.4.2. Midpoint Characterization Factors.** For GLO Exposure Risks, the M-CF is established
33 separately for each unit process in the study scope in a different location. The M-CF
34 characterizes the exposure of humans to GLO at concentrations exceeding the 60 ppb threshold.
35 The M-CF must be assessed using Geographic Information System tools and dispersion
36 modeling. It is calculated by first assessing the Exposure Risk Factor for GLO (ERF_{GLO}), by grid
37 cell, in the region of the operation. The ERF_{GLO} is calculated using Equation 6.1.

38 **Equation 6.1. Calculation for the Exposure Risk Factor for GLO Exposure Risks for a single grid cell. The ERF_{GLO} is in**
39 **units of persons * ppb O₃ * hours.**

⁵⁴ Fry, M.M. The influence of ozone precursor emissions from four world regions on tropospheric composition and radiative climate forcing.

⁵⁵ Fry, M.M. The influence of ozone precursor emissions from four world regions on tropospheric composition and radiative climate forcing.

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$$ERF_{GLO} \text{ for a grid cell} = \frac{1}{480 \text{ ppb} * \text{hrs}_{\text{ozone season}}} \times \sum_{\text{daylight hours}_{\text{ozone season}}} (O_3 \text{ ambient concentration (ppb)} - 60 \text{ ppb}) \times \sum_{\text{hours}} (\text{Population} \times O_3 \text{ concentration (ppb) from dispersion})$$

M-CFs for an operation is then calculated as the sum of the ERF_{GLO} by grid cell across the dispersion domain for the operation, which is the region into which ozone formed from precursors emitted from the operation transit. The dispersion domain shall be calculated using air dispersion modeling. The same air dispersion model and data must be used as for the assessment of Regional Acidification. The M-CF must be assessed using the same approach for all unit processes.

Assessment of M-CFs should not be completed for all operations in the supply chain, as this is impractical. Instead, M-CFs should be assessed using the following specific approach, in order to minimize the effort required:

- After the initial LCI model is completed, LCA results shall be assessed using PP-CFs with no M-CFs. No regionalization is required.
- The preliminary set of key unit processes (i.e., processes contributing over 15% to results) should be identified based on results using PP-CFs.
- Unit processes which are located in regions with elevated GLO concentrations, should be identified. This can include regions in non-attainment areas, or in overseas regions without stringent air quality regulations (e.g., urban areas in China or India). Unit processes located in these regions could be significant contributors to results, and should be added to the preliminary list of “key” unit processes.
- The location of all preliminary key unit processes should be determined. Based on their location, readily available M-CFs (e.g. those derived from previous studies) should be used to assess results where possible. For unit processes for which readily available M-CFs do not exist, representative M-CFs (i.e., defined based on M-CFs for nearby unit processes, or using a conservatively high values), can be used.
- M-CFs should then be generated with dispersion models only for the remaining key unit processes, in order to assess final results.
- With this approach, typically 5-10 M-CFs need to be evaluated for each supply chain in order to assess results of acceptable data quality. For the processes for which M-CFs are not established, conservative estimates can be used to establish results. Uncertainty and data quality analysis can assist in the effort to minimize the number of M-CFs which are established.

In cases where consistent GIS tools and data are unavailable for all key unit operations which are identified, and the use of representative M-CFs is not possible, results cannot be evaluated.

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1 Regional ozone concentrations and population densities vary by multiple orders of magnitude
2 even within single countries, and assessing results in terms of mass of emitted NO_x or other
3 modes can be misleading. In cases where full assessment is not possible, indicator results shall
4 be reported as “No data”.

5 **7.1.5. Indicator Equation and Unit of Measure.** The category indicator result (at Node 4) for
6 GLO Exposure Risks is shown in Equation 6.2, for a single unit process. The indicator result is
7 expressed in units of persons * ppb O₃ * hours.

8 Equation 6.2. **Indicator equation for a single unit process for GLO Exposure Risks, characterized at Node 4.**

$$\text{GLO Exposure Risks} = \sum_n (\text{Precursor emissions}_n \times \text{PP-CF}_n \times \text{M-CF})$$

Where:

- *n represents the total number of ozone precursors emitted by a unit process.*
- *PP-CF_n characterizes the chemical transformation of precursor emissions to O₃.*
- *M-CF characterizes the exposed population over threshold, as well as the severity of the threshold exceedance, over the course of the ozone season.*

9
10 **7.2. Particulate Matter (PM2.5) Exposure Risks**

11 **7.2.1. Impact Category.** The impact category for PM2.5 Exposure Risks considers human
12 health impacts which could result from exposure to particulates under 2.5 micrometers in
13 diameter. These risks of exposure are linked to emission of particulates as well as secondary
14 aerosol particle precursor releases (sulfate and nitrate aerosols formed from SO_x and NO_x
15 emissions, respectively).

16
17 **7.2.1.1. Definition of Threshold Exceedance for PM2.5 Exposure Risks.** Although for GLO
18 Exposure Risks, clear thresholds have been identified for concentrations of GLO above which
19 sensitive populations can experience health effects, the preponderance of evidence shows that
20 there is no threshold for particulate concentrations below which no adverse health effects
21 would be anticipated. According to the World Health Organization, adverse health effects
22 resulting from PM2.5 exposures have been demonstrated at concentrations not greatly above
23 the background concentration, which is roughly 3 µg PM2.5/m³ in the United States and
24 Western Europe.⁵⁶ Accordingly, there is no relevant health threshold for PM2.5 Exposure Risks.

25
26 However, in practice, it may be useful to use an operational threshold of 1 µg PM2.5/m³ for PM2.5.
27 By including in the scope only those areas with elevated PM2.5 concentrations, this will simplify
28 computations greatly, although results will not be significantly affected.

⁵⁶ World Health Organization, 2006. *WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Global update 2005.*

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1 **7.2.2. Stressor-Effects Network.** The stressor effects network for PM2.5 Exposure Risks is
2 shown in Table 7. 2 of Annex B. The spatial extent, severity, and duration, of the midpoints in
3 the stressor-effects network will vary significantly based upon the region of emission, season of
4 emission, emission type, and other considerations. Site-specific assessment of category
5 indicators in this impact category is required, in order to reflect this regional variability. The
6 use of representative data in characterization can help to guide characterization during the
7 iterative process, but could lead to significant uncertainties which may compromise the ability
8 to achieve the goals of the LCA study.
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7.2.2.1. Selection of Category Indicator. For this impact category, one category indicator is assessed, for PM2.5 Exposure Risks. The category indicator shall be at Node 3 if data is available, characterizing the contribution to the severity of risks of exposure to regional populations from PM2.5. A detailed description of the characterization model is provided in Section 6.2.4.

In some cases, data may be unavailable to assess results at Node 3. This may be due to a lack of data regarding the locations of unit process(es) in the anthropogenic system, lack of data for dispersion modeling, or lack of population density maps. Due to the high variability in the stressor-effects network for this impact category, results at Node 1 have very low environmental relevance, and could be misleading. If results cannot be assessed at Node 3, results for PM2.5 Exposure Risks should be reported as “No data.”

7.2.2.2. Identifying Core Impact Categories and Category Indicators. As there is no relevant health threshold, PM2.5 Exposure Risks is relevant for any unit process(es) in the anthropogenic system which emit primary particulates or secondary particulate precursors that contribute to the elevation of PM2.5 concentrations and subsequent risks of exposure to regional populations.

When considering the anthropogenic system as a whole, PM2.5 Exposure Risks will be a relevant impact category in almost all cases, and this impact category can initially be assumed to relevant for a given LCA study. Anthropogenic systems almost always will include unit process(es) which emit particulates or precursors into regions which can affect regional populations.

7.2.3. Classification. All primary particulate matter and secondary particulate matter precursors are classified in this indicator.

7.2.4. Characterization.

7.2.4.1. Potency Potential Characterization Factors. The PP-CF for PM2.5 Exposure Risks characterizes the mass of PM2.5 transported in the atmosphere as the result of an emission. For emissions of primary particulates, the PP-CF characterizes the fraction of PM2.5. For emissions of secondary particulate precursors (SO_x and NO_x), the PP-CF characterizes the amount of PM2.5 formed from different atmospheric processes.

The conversion rates of precursors depend on atmospheric and meteorological conditions; the fraction of particulates that are PM2.5 (i.e., less than 2.5 microns in diameter) can also depend upon the fuel type used in combustion. The basis of PP-CFs used shall be described and justified in the LCA report. The PP-CF values in Table 6. 1 can be used as a default if no specific information is available.

Table 6. 1. PP-CFs used in calculation of category indicator results for PM_{2.5}.

Emission	Potency Potential Characterization Factor <i>(ton PM_{2.5} eq. per ton emission)</i>
≤ PM 2.5	1
> PM 2.5	0
PM10 and unspecified PM	0.9
SO ₂ *	0.36
NO _x **	0.10

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*Emissions of all oxides of sulfur are characterized with PP-CF for SO₂.

**Emissions of all oxides of nitrogen are characterization with PP-CF for NO_x. This includes emissions of nitrogen dioxide, nitrogen monoxide, and unspecified nitrogen oxides.

7.2.4.2. Midpoint Characterization Factors. For PM_{2.5} Exposure Risks, the M-CF is established separately for each unit process in the study scope in a different location.

The M-CF characterizes the exposure of humans to fine particulate matter, considering the local severity of health impacts linked to elevated levels of PM_{2.5}. The M-CF differs by process in the supply chain, which must be assessed using GIS tools and dispersion modeling. It is calculated by first assessing the Exposure Risk Factor for PM_{2.5} (ERF_{PM2.5}), by grid cell, in the region of the operation. The ERF_{PM2.5} is calculated using Equation .

Equation 7.2. Calculation for the Exposure Risk Factor for PM_{2.5} for a single grid cell.

$$ERF_{PM_{2.5}} \text{ for a grid cell} = \frac{\text{Annual average ambient concentration } \left(\frac{\mu\text{g } PM_{2.5}}{m^3} \right)}{\sum_{hours}^{year} \left(3 \frac{\mu\text{g } PM_{2.5}}{m^3} \right)}$$
$$x \sum_{hours}^{year} \left(\text{Population } x \text{ } PM_{2.5} \text{ concentration from dispersion } \left(\frac{\mu\text{g } PM_{2.5}}{m^3} \right) \right)$$

M-CFs for an operation are then calculated as the sum of the ERF_{PM2.5} by grid cell across the dispersion domain for the operation, which is the region into which PM_{2.5} and PM_{2.5} precursors emitted from the operation transit. The dispersion domain shall be calculated using air dispersion modeling. The same air dispersion model and data must be used as for the assessment of Regional Acidification and GLO Exposure Risks. The M-CF must be assessed using the same approach for all unit processes.

Assessment of M-CFs should not be completed for all operations in the supply chain, as this is impractical. Instead, M-CFs should be assessed using the following specific approach, in order to minimize the effort required:

- After the initial LCI model is completed, LCA results shall be assessed using PP-CFs with no M-CFs. No regionalization is required.
- The preliminary set of key unit processes (i.e., processes contributing over 15% to results) should be identified based on results using PP-CFs.
- Unit processes which are located in regions with elevated PM_{2.5} concentrations, should be identified. This can include regions in non-attainment areas, or in overseas regions without stringent air quality regulations (e.g., urban areas in China or India). Unit processes located in these regions could be significant contributors to results, and should be added to the preliminary list of “key” unit processes.
- The location of all preliminary “key” unit processes should be determined.

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- 1 • M-CFs should then be evaluated only for the key unit processes, in order to assess final
2 results.
- 3 • With this approach, typically 5-10 M-CFs need to be evaluated for each supply chain in
4 order to assess results of acceptable data quality. For the processes for which M-CFs are not
5 established, conservative estimates can be used to establish results.
- 6 • Uncertainty and data quality analysis can further assist in the effort to minimize the number
7 of M-CFs which are established.

8 In cases where GIS tools and data are unavailable, results cannot be evaluated. Regional PM_{2.5}
9 concentrations and populations vary by multiple orders of magnitude even within single
10 countries, and assessing results in terms of mass of emitted PM_{2.5} or other modes can be
11 misleading. In cases where full assessment is not possible, indicator results shall be reported as
12 “No data”.

13
14 In practice, there may be cases where site-specific M-CFs cannot be determined for unit
15 process(es) in the study scope, and the use of representative M-CFs results in a significant effect
16 on data quality of results which makes it impossible to achieve the goals of the LCA study. In these
17 cases, the goal and scope may need to be revised.

18
19 **7.2.5. Indicator Equation and Unit of Measure.** The category indicator result (at Node 3) for
20 PM2.5 Exposure Risks is shown in Equation 6.5, for a single unit process. The indicator result is
21 expressed in units of persons * µg PM2.5 eq. / m³ * hours.

22 **Equation 6.5. Indicator equation for a single unit process for PM2.5 Exposure Risks, characterized at Node 3**
23 **(contribution to risks of PM2.5 exposure).**

$$\text{PM2.5 Exposure Risks} = \sum_n (\text{Emissions}_n \times \text{PP-CF}_n \times \text{M-CF})$$

Where:

- *n* represents the total number of particulates and aerosol particle precursors emitted by a unit process
- *Emissions* are particulates and aerosol particle precursors emitted by a unit process
- *PP-CF* is the amount of PM2.5 which transports throughout the dispersion domain as the result of the emission
- *M-CF* represents exposed population, as well as the severity of the exposure

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1 **7.3. Ambient Air Exposures to Hazardous Chemicals**

2
3 **7.3.1. Impact Category.** This impact category considers emissions to air of hazardous ambient
4 air contaminants (HAACs) from unit process(es) in the anthropogenic system, which can
5 result in risks of human exposure through inhalation in ambient air.

6
7 Depending on the type of unit process considered, there are many types of emissions that could
8 be relevant, including organic chemicals, heavy metals, and other substances. Most commonly,
9 exposure occurs on a chronic basis, as human populations are exposed to concentrations of
10 HAACs exceeding health thresholds over long periods of time.

11
12 The scale, severity, and duration of risks of human exposure through inhalation due to the
13 increased concentrations of HAACs will vary broadly, depending on factors such as the chemical
14 species emitted, local population density, unit process type, scale of emission, timing of emission,
15 regional topography, climate, weather patterns, and other characteristics of the region in which
16 an emission occurs. The midpoints and endpoints associated with this impact category vary for
17 all of these reasons. Accordingly, site-specific assessment of HAAC Exposure Risks is required.
18 Secondary data shall not be used in the assessment of this impact category.

19
20 **7.3.1.1. Definition of Hazardous Ambient Air Contaminant.** For this impact category, HAACs
21 are those contaminants which have the potential to expose humans via inhalation in ambient
22 air, and which have been observed to cause adverse effects if humans are exposed to air
23 concentrations over health thresholds.

24
25 At the outset of the study, the set of HAACs considered should be clearly defined. HAACs should
26 include those substances which have exposed humans in the past in ambient air over health
27 thresholds. The set of HAACs considered can be based upon lists of regulated emissions
28 developed by government agencies.

29 *For example.* To define a set of HAACs, the hazardous air pollutants defined by the United States
30 Environmental Protection Agency could be used.

31
32 For a given LCA study, the set of HAACs will be screened to identify those emission sources which
33 are relevant for HAAC Exposure Risks (see Section 7.3.2.2).

34
35 **7.3.1.2. Definition of Threshold Exceedance for HAAC Exposure Risks.** For a given HAAC,
36 the health threshold is a concentration in ambient air, usually expressed in units of $\mu\text{g}/\text{m}^3$ or
37 ppb. A region is in exceedance of threshold if ambient concentrations of the HAAC exceed this
38 threshold. If emissions are found to be relevant in this impact category based on the
39 requirements of Section 7.3.2.2, the threshold used, and basis of the threshold, shall be
40 described in the LCA report.

41
42 The health threshold for a given HAAC is the maximum safe ambient air concentration of the
43 HAAC at which a continuous inhalation exposure to the human population is likely to be without
44 an appreciable risk of deleterious effects during a lifetime.

45
46 Whenever possible, the health threshold for an HAAC should be based upon published estimates
47 of the maximum safe ambient air concentration. The health threshold can be based upon the

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1 Reference Concentration for Chronic Inhalation Exposure (RfC); RfCs are provided for many
2 HAACs in the US EPA Integrated Risk Information System database.⁵⁷
3

4 If published estimates of the maximum safe ambient air concentration do not exist for an HAAC,
5 the health threshold must be estimated. The health threshold shall be derived from a NOAEL (no-
6 observed-adverse-effects level), LOAEL (lowest-observed-adverse-effects-level), or benchmark
7 concentration, with uncertainty factors applied to reflect limitations of the data used.

8 NOTE. If NOAELs, LOAELs, or benchmark concentrations, are used directly to estimate the health threshold
9 for a given HAAC, the appropriate statistical interpretation of these measures must be taken into account.
10 NOAELs and LOAELs are not direct estimates of a threshold level for adverse effects in humans resulting
11 from exposure. For example, a NOAEL from a specific study could in fact result in significant, yet undetected
12 incidence of adverse effects in the exposed population; or alternatively, the NOAEL could be significantly
13 lower than the actual threshold level.⁵⁸ Conservative assumptions shall be made to account for uncertainty
14 in NOAEL and LOAELs, using uncertainty and extrapolation factors, based on the approach used by the US
15 EPA to define RfCs in non-cancer assessments.
16

17 For some HAACs, the onset of adverse effects after exposure may occur at levels which are
18 so low they cannot be defined (e.g., for known carcinogens). This means that there is no
19 measurable ambient air concentration which is safe. In these cases, the health threshold can
20 be defined operationally as the lowest air concentration at which the HAAC can be detected
21 on a routine basis.
22

23 **7.3.1.2.1. Threshold Exceedance for Mixtures of HAACs.** In many cases, populations will be
24 exposed to multiple HAACs in the same receiving environment (i.e., as mixtures). If the HAACs
25 have similar modes of action, the combined exposure could result in observed health endpoints
26 in the exposed population, even if no individual HAAC is present at concentrations over its
27 specific threshold.
28

29 In these cases, the World Health Organization/International Programme on Chemical Safety
30 framework for risk assessment of combined exposure to multiple chemicals⁵⁹ should be used to
31 define an applicable threshold for a given receiving environment, considering the HAACs which
32 are present in the region. The Tier 1 approach from this WHO/IPCS framework is recommended
33 for LCA, where regions are considered to be in exceedance of threshold if the hazard index (i.e.,
34 the sum of the ratios of ambient concentrations to specific health thresholds for all relevant
35 HAACs) is greater than one, considering data uncertainty. The approach used to define
36 exceedance of threshold shall be described in the LCA report.

37 NOTE. The Tier 1 approach, based on the sum of hazard indices, is used by the US EPA in the National-Scale
38 Air Toxics Assessment (NATA) for its assessment of non-cancer health risks, which identified locations in
39 the US that are of greatest potential concern in terms of contributing to population risk from exposure to
40 HAACs.

⁵⁷ Based on definition from US EPA Risk Assessment Glossary.

⁵⁸ California Environmental Protection Agency: Office of Environmental Health Hazard Assessment. *Air Toxics Hot Spots Program: Risk Assessment Guidelines, Part III: Technical Support Document*. February 2000.

⁵⁹ Meek, M.E., et al. *Risk assessment of combined exposure to multiple chemicals: A WHO/IPCS framework*. Regulatory Toxicology and Pharmacology 60 (2011) S1-S14.

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1
2
3 **7.3.2. Stressor-Effects Network.** The stressor-effects network for this impact category is shown
4 in Table 7.3 of Annex B. The specific spatial scale, number of people exposed, and severity of risks
5 of human exposures over threshold can vary greatly based on type and the region of emission.
6

7 Analysis of the risks of human exposures to concentrations of HAACs over health thresholds
8 (Node 3 in Table 7.3 in Annex B) is necessary to determine if exposure risks to humans are linked
9 to emissions from a given unit process. If human exposure to HAACs can be documented as a
10 relevant impact category (according to requirements of Section 7.3.2.2), the unit processes and
11 HAACs resulting in exposure, along with the human health endpoints that can result from an
12 exposure, should be understood and described in the LCA report, and in EPDs and C-EPDs which
13 are generated.

14 For emissions of certain persistent chemicals, emissions to ambient air can result eventually in
15 risks of exposure by ingestion, if the substance considered transfers to water and/or soils where
16 it could eventually be ingested through contamination of food and/or water. If midpoints and
17 endpoints in the stressor-effects network, and characterization models used, are distinct for the
18 routes of both inhalation (ambient air) and ingestion, then category indicators in this impact
19 category, and for the impact category of Hazardous Chemical Exposure Risks (ingestion), will be
20 relevant and should be reported separately.
21

22 **7.3.2.1. Selection of Category Indicator(s).** After identifying all emissions of HAACs which
23 are relevant in this impact category according to Section 7.3.2.2, distinct category indicators
24 are defined.
25

26 To define these distinct category indicators, the stressor-effects network for emissions of
27 each HAAC should first be considered separately. Separate category indicators shall be
28 reported for each HAAC emitted under the following conditions:
29

- 30
- 31 • The mode of action and/or human health endpoints associated with inhalation of the
32 HAAC is distinct in character, temporal duration, severity, persistence, reversibility,
33 or other aspects.
 - 34 • Midpoints or endpoints in the stressor-effects network are significantly different in
35 spatial scale, temporal scale, severity of exposures, or other considerations.
 - 36 • The characterization model used to assess category indicator results is distinct.

37 Aggregation of emissions of different HAACs into a single category indicator is only possible
38 if there are consistent measures of inhalation toxicity available for use as the basis for PP-
39 CFs. If there is no scientific basis for aggregating multiple HAACs using PP-CFs (see Section
40 7.3.4.1), multiple category indicators must be reported.
41

42 Ideally, the midpoint selected for the category indicator would be Node 3, representing
43 contribution to risk of exposure to HAACs at levels exceeding health thresholds. A
44 characterization model is not established in this Standard for characterization at Node 2 or
45 higher nodes. Characterization at Node 1 measures levels of emissions into ambient air.
46

47 NOTE. This does not preclude the establishment of characterization models at Node 2 or
48 higher in specific LCA studies. If results are characterized at Node 2 or higher, the basis
49 of data sources and modeling must be described in the LCA report. The uncertainty in any

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1 data sources and models must be considered. As characterization models become
2 established and more broadly available, these may be incorporated into future versions
3 of this Standard.

4
5 Characterization at Node 1 has low environmental relevance. This low environmental
6 relevance shall be described in the LCA report, and wherever results are reported.

7
8 **7.3.2.2. Identifying Core Impact Categories and Category Indicator(s).** Due to the
9 extensive data collection and analysis required to characterize category indicators for HAAC
10 Exposure Risks, it is essential to carefully screen the anthropogenic system under study to
11 identify the unit processes contributing to risks of human exposures to HAACs in regions in
12 exceedance of threshold. This screening minimizes the amount of data collection required.

13
14 NOTE. Although characterization takes place at Node 1, the determination of the
15 relevance of this impact category is based on a screening of the linkage of emissions to
16 the midpoint at Node 3, representing the risks of exposure to humans from inhalation of
17 HAACs in regions in exceedance of threshold.

18
19 HAAC Exposure Risks shall only be considered relevant for a given HAAC emitted from a given
20 unit process, if the emission satisfies the following conditions:

- 21
- 22 • The given HAAC has been detected in ambient air at concentrations over the defined
23 health threshold in the region of emission. The health threshold is defined for a HAAC
24 according to the requirements of Section 7.3.1.2., or
 - 25 • The HAAC has been detected in ambient air in a mixture with other HAACS with
26 similar modes of action in regions in exceedance of threshold according to Section
27 7.3.1.2.1.; and
 - 28 • The emission of the HAAC at the given unit process contributes to increased
29 concentrations in ambient air in the region of emission.
- 30

31 As part of the iterative process, those unit processes which result in significant emissions of
32 HAACs to air should be identified; it can then be determined if these emissions transport into
33 regions where health thresholds have are exceeded. This type of ambient monitoring data is
34 often readily available from governmental monitoring programs or in published literature.
35 Dispersion modeling may be required to determine if emissions contribute to specific
36 instances of polluted ambient air.

37
38 If a unit process has been determined to exist in a region which has been determined to be in
39 exceedance of threshold, and the unit process has associated emissions of the HAAC, the
40 emission still must be linked to the increased concentration of that HAAC. The expected
41 transport distance and residence time of the HAAC in question, as well as the proximity of the
42 emission source to potentially exposed populations, must be considered.

43
44 Whether this impact category is included as relevant depends on the goal and scope of the
45 LCA study. When screening to determine if HAAC Exposure Risks is a core impact category,
46 the scale of the functional unit used shall be large enough to include observed instances of
47 midpoints of ambient air with HAAC concentrations over threshold. The functional unit
48 should be scaled based upon the gross scale of emission levels in the anthropogenic system.
49 The functional unit must not be set arbitrarily low, which could rule out this impact category

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1 even in cases where HAAC Exposure Risks are occurring and can be linked to emissions from
2 the anthropogenic system. This screening may require sensitivity analysis.
3

4 NOTE. If specific data is unavailable for gross emissions, gross emissions can be estimated using
5 conservative assumptions. This impact category is not relevant if emission levels of HAACs are negligible,
6 even when considering the gross scale of emissions estimated using conservative assumptions.
7

8 The justification for the inclusion or exclusion of this impact category shall be provided in the
9 LCA report.
10

11 The initial screening for relevance of HAAC Exposure Risks may determine that the scale of
12 the functional unit needs revision, or that the goal and/or scope needs revision in other ways.
13 The exclusion of this impact category should be a key subject of the critical review phase.
14

15 NOTE. Although the number of HAACs emitted from a anthropogenic system may be significant, in practice,
16 very few emissions will be of a nature and scale that human exposure from inhalation in ambient air will
17 result. Very few contaminants with inherent toxic properties are emitted in sufficient volume to warrant
18 inclusion as relevant. Furthermore, there are many regions not in exceedance of threshold. The screening
19 for this impact category should be able to quickly determine if this impact category is relevant to unit
20 processes in the anthropogenic system. An efficient screening will require expert judgment and sensitivity
21 analysis to guide the iterative process.
22

23 **7.3.3. Classification.** HAACs presenting a risk of exposure through inhalation of ambient air are
24 classified. This includes all emissions of HAACs meeting the requirements of Section 7.3.2.2.
25

26 **7.3.4. Characterization.**
27

28 **7.3.4.1. Potency Potential Characterization Factors.** The PP-CF is specific to a given HAAC,
29 and is separately defined for each category indicator included in the study scope.
30

31 In cases where multiple types of HAACs are considered in a single category indicator, the PP-CF
32 characterizes the inhalation toxicity of each HAAC. This PP-CF can be defined as this inhalation
33 toxicity in relation to the inhalation toxicity of a reference contaminant with similar human health
34 endpoints. For each category indicator, the same reference contaminant, and consistent
35 measures of inhalation toxicity, must be used.
36

37 NOTE. For category indicators that only include emissions of a single HAAC, the HAAC is
38 its own reference contaminant.
39

40 The PP-CF for this impact category can be calculated using Equation 7.6.
41

42 **Equation 7.6. Potency Potential Characterization Factor for HAAC Exposure Risks.**

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$$S - CF_i = \frac{\text{inhalation toxicity}_i}{\text{inhalation toxicity}_{reference}}$$

Where:

- *PP-CF is the Potency Potential Characterization Factor for a given HAAC, denoted i*
- *Inhalation toxicity is the measure of the inhalation toxicity for the given contaminant (denoted i), and the reference contaminant.*

1
2
3 NOTE. Emissions levels multiplied by the PP-CF in Equation 7.6 gives results in units of
4 equivalent mass of the reference contaminant. The PP-CF equation will depend upon the
5 units of the measures of inhalation toxicity that are used.
6

7 For HAACs which have a clear dose threshold for onset of toxic health effects, the inhalation
8 toxicity can be characterized using the lowest inhalation exposure threshold linked to onset
9 of the critical toxic effect. This is typically measured in milligrams / cubic meter for daily
10 inhalation exposure.
11

12 NOTE. The Reference Concentration for Chronic Inhalation Exposure (RfC) for an HAAC,
13 from the US Environmental Protection Agency's Integrated Risk Information System
14 database, can be used to characterize the PP-CF for HAACs which have toxic effects that
15 have a dose threshold for onset.
16

17 However, for many HAACs, there is no clear dose threshold for onset. In these cases, extreme
18 care must be taken in defining the inhalation toxicity of different HAACs and the reference
19 contaminant, in order to provide a defensible basis of aggregation for multiple HAACs into a
20 single category indicator.
21

22 FOR EXAMPLE. Carcinogenicity is a toxic effect that does not exhibit a clear threshold
23 for onset. PP-CFs for carcinogenicity must be represented by measures such as Inhalation
24 Unit Risk.
25

26 If there is no scientifically defensible basis for assessing PP-CFs for multiple HAACs based on
27 consistent measures of inhalation toxicity, there is no way to aggregate emissions into a single
28 category indicator. In these cases, separate category indicators must be reported for each
29 emission.
30

31 NOTE. The lack of a consistent basis for aggregation may indicate that the toxic
32 endpoints and/or modes of action of HAACs are different, and/or that the stressor-effects
33 networks are distinct.
34

35 For HAACs exhibiting toxic effects with a clear dose threshold for inhalation, measures based
36 on the onset of the critical toxic effect are the most widely used, as these measures usually
37 contain the least inherent uncertainty. However, even these measures can contain inherent
38 uncertainties of one order of magnitude or more. When deriving PP-CFs, the uncertainty in
39 the measure of inhalation toxicity should be considered in the context of the goal and scope
40 of the study. If the uncertainty in the PP-CFs are very high, it may not be possible to achieve
41 the goals of the study. In these cases, the goal and scope may need to be revised.

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1
2 The measures of inhalation toxicity used must be based upon empirical measurements from
3 peer-reviewed studies. Generic extrapolation between measures, such as the lowest onset
4 threshold for the critical toxic effect and the median effective dose (ED50) value for a given
5 HAAC, shall not be used.

6
7 **7.3.4.2 Midpoint Characterization Factors.** For category indicators in this impact category,
8 characterization models for nodes higher than Node 1 have not been established (see Section
9 6.3.2). There is no M-CF for characterization at Node 1.

10
11 **7.3.5. Indicator Equation and Unit of Measure.** Results (at Node 1) are calculated using
12 Equation 6.7. Results calculated using Equation 7.7 are reported in units of mass equivalents of
13 the reference contaminant.

14
15 **Equation 7.7. Indicator equation for a single unit process for HAAC Exposure Risks, with results**
16 **reported at Node 1 (emissions levels).**

$$\text{HAAC Emissions} = \sum_i (\text{Emissions}_i \times \text{PP-CF}_i)$$

Where:

- *Emissions_i are the emissions levels of a given HAAC, reported in units of mass.*
- *PP-CF_i is the Potency Potential Characterization Factor for each HAAC, representing its inhalation toxicity relative to the reference contaminant.*

17
18 **7.3.6. Additional Reporting Requirements.** The terminology used to describe category
19 indicator results shall be descriptive of the characterization model which is used. Terminology
20 which overstates the environmental relevance of the result shall not be used.

21
22 **7.3.7. Addressing Additional Limitations in Types, Accuracy, and Availability of**
23 **Environmental Data.** The first step in characterization of results in this impact category is the
24 screening for determination of relevance of emissions, according to the requirements and
25 guidance provided in Section 7.3.2. In some anthropogenic systems, where unit process(es) are
26 distributed in extensive global supply chains, lax regulations and poor monitoring in certain
27 regions might make it impossible to determine the relevance of specific emissions sources to
28 this impact category. If the screening cannot be conducted, then determination of the relevance
29 of this impact category may not be possible; this could affect the ability to achieve the goals of
30 the LCA study. If the relevance of this impact category cannot be determined, the goal and scope
31 of the LCA study may need to be revised.

32
33 In some cases, no data will exist to determine the inhalation toxicity or maximum safe ambient
34 air concentration of HAACs which are emitted by unit processes in the anthropogenic system, and
35 which have been detected in ambient air at elevated concentrations near population centers. In
36 these cases, it may not be possible to determine if emissions of the HAAC could be linked to
37 human health impacts, and it will not be possible to aggregate these emissions using PP-CFs. In
38 these cases, the effect on final results should be considered, and documented as a limitation in
39 the LCA report. Emissions of these HAACs should be documented in the LCA report. If the HAAC
40 emissions from given unit processes are significant, and contribute to regions where

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1 concentrations of the HAAC are problematic, it may not be possible to achieve the goals of the
2 study. The goal and scope of the LCA study may need to be revised.
3
4

5 **7.4. Indoor Air Exposures to Hazardous Chemicals**

6
7 **7.4.1. Impact Category.** This impact category considers emissions to air of hazardous indoor
8 air contaminants (HIACs) from unit process(es) that transport into indoor environments
9 and can result in risks of human exposure through inhalation.
10

11 Depending on the type of unit process considered, many types of emissions can be relevant,
12 including volatile organic chemicals (VOCs), semi-volatile organic chemicals (SVOCs), dust, and
13 emissions of other contaminants. In some cases, ambient pollutants from outdoor emissions can
14 enter indoor environments as well.
15

16 Most commonly, exposure occurs on a chronic basis, as occupants of indoor settings are exposed
17 to concentrations of HIACs over long periods of time.
18

19 NOTE. In rare instances, acute exposures to high concentrations of HIACs can occur, usually
20 as a result of accidents or spills in certain types of industrial facilities. However, in the
21 majority of cases, individuals are exposed daily to substances in confined indoor spaces, often
22 for extended periods of time, resulting in chronic risks of exposure; this indicator focuses on
23 these chronic risks.
24

25 The scale, severity, timing, and duration of risks of human exposure through inhalation in indoor
26 settings will vary broadly, depending on factors such as the HIAC which is emitted, unit process
27 type, scale of emission, timing of emission, ventilation rates, and other characteristics of the
28 indoor setting. The midpoints and endpoints associated with this impact category vary for all of
29 these reasons. Accordingly, site-specific assessment of HIAC Exposure Risks associated with a
30 unit process is required. Secondary data shall not be used in the assessment of this impact
31 category.
32

33 **7.4.1.1. Definition of Hazardous Indoor Air Contaminant.** For this impact category, HIACs
34 are those contaminants which have the potential to expose humans via inhalation in indoor air,
35 and which have been observed to cause adverse effects if humans are exposed to air
36 concentrations over health thresholds.
37

38 At the outset of the study, the set of HIACs considered should be clearly defined. HIACs should
39 include those substances which have exposed humans in the past in indoor air over health
40 thresholds. The set of HIACs considered can be based upon lists of target emissions covered in
41 voluntary standards or regulations regarding indoor air.

42 **For example.** The set of HIACs considered can be based upon target VOCs can be from *The Standard Method*
43 *for the Testing and Evaluation of Volatile Organic Chemical Emissions from Indoor Sources Using*
44 *Environmental Chambers*, the emission testing method for the California Specification 01350.
45

46 For a given LCA study, the set of HIACs will be screened to identify those emission sources which
47 are relevant for HIAC Exposure Risks (see Section 7.4.2.2).

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1
2 **7.4.1.2. Definition of Threshold Exceedance for HIAC Exposure Risks.** For a given HIAC, the
3 health threshold is a concentration in indoor air, usually expressed in units of $\mu\text{g}/\text{m}^3$ or ppb.
4 Indoor environments are defined to be in exceedance of threshold if the concentration of an
5 HIAC exceeds this health threshold. If emissions are found to be relevant in this impact
6 category based on the requirements of Section 7.4.2.2, the threshold used, and basis of the
7 threshold, shall be described in the LCA report.

8
9 The health threshold for a given HIAC is the maximum safe indoor air concentration of the HIAC
10 at which a continuous inhalation exposure to the human population is likely to be without an
11 appreciable risk of deleterious effects during a lifetime.

12
13 Whenever possible, the health threshold for an HIAC should be based upon published estimates
14 of the maximum safe indoor air concentration. The health threshold can be based upon the
15 Chronic Reference Exposure Level (CREL);⁶⁰ CRELs are provided for many HIACs by the State of
16 California Office of Environmental Health Hazard Assessment (OEHHA). If a CREL is not available
17 for a given HIAC, the RfC can be used (see Section 7.3.1.2).

18
19 If published estimates of the maximum safe indoor air concentration do not exist for an HIAC, the
20 health threshold must be estimated. The health threshold shall be derived from a NOAEL (no-
21 observed-adverse-effects level), LOAEL (lowest-observed-adverse-effects-level), or benchmark
22 concentration, with uncertainty factors applied to reflect limitations of the data used.

23 NOTE. If NOAELs, LOAELs, or benchmark concentrations, are used directly to estimate the health threshold
24 for a given HAAC, the appropriate statistical interpretation of these measures must be taken into account.
25 NOAELs and LOAELs are not direct estimates of a threshold level for adverse effects in humans resulting
26 from exposure. For example, a NOAEL from a specific study could in fact result in significant, yet undetected
27 incidence of adverse effects in the exposed population; or alternatively, the NOAEL could be significantly
28 lower than the actual threshold level.⁶¹ Conservative assumptions shall be made to account for uncertainty
29 in NOAEL and LOAELs, using uncertainty and extrapolation factors, based on the approach used by the
30 OEHHA to define CRELs.

31
32 For some HIACs, the onset of adverse effects after exposure may occur at levels which are so
33 low they cannot be defined (e.g., for known carcinogens). In these cases, the health threshold
34 can be defined operationally as the lowest air concentration at which the HIAC can be
35 detected on a routine basis.

⁶⁰ California Environmental Protection Agency: Office of Environmental Health Hazard Assessment. *Air Toxics Hot Spots Program: Risk Assessment Guidelines, Part III: Technical Support Document.* February 2000.

⁶¹ California Environmental Protection Agency: Office of Environmental Health Hazard Assessment. *Air Toxics Hot Spots Program: Risk Assessment Guidelines, Part III: Technical Support Document.* February 2000.

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1 **7.4.1.2.1. Threshold Exceedance for Mixtures of HIACs.** In some cases, exposure to multiple
2 HIACs in the same indoor environment could occur (i.e., as mixtures). If the HIACs have similar
3 modes of action, the combined exposure could result in observed health endpoints in the
4 exposed population, even if no individual HIAC is present at concentrations over its specific
5 threshold. The approach for determining if an indoor environment is in exceedance of threshold
6 should consider the effect of such mixtures.

7 **FOR EXAMPLE.** The World Health Organization/International Programme on Chemical Safety framework
8 for risk assessment of combined exposure to multiple chemicals⁶² could be used to define an applicable
9 threshold, considering all of the HIACs present in the local receiving environment.

10
11 **7.4.2. Stressor-Effects Network.** The stressor-effects network for this impact category depends
12 upon the size, location, timing, duration, and indoor setting of an emission; the resulting scale,
13 severity, timing, and duration of midpoints of concentrations of HIACs will vary for many reasons.
14 The stressor-effects network for this impact category, shown in Table 7. 4 in Annex B, provides a
15 general framework; however, for each separate indicator included, a separate stressor-effects
16 network shall be modeled. This model should consider the site-specific circumstances of
17 stressors, midpoints, and endpoints, in the cause-effect relationship resulting from the emission
18 source. This will greatly aid in the characterization of results, and ensure that relevant impacts
19 are identified.

20
21 NOTE. This stressor-effects network is nearly always linked to emissions of HIACs directly
22 into indoor settings; however, ambient pollutants can in some cases transport into indoor
23 settings, and outdoor emissions in some instances must therefore be considered.

24
25 The midpoint at Node 3, risks of human exposures to concentrations of HIACs exceeding health
26 thresholds (Table 7. 4 in Annex B), is important to understand. For a given unit process, the
27 contaminants, level of contamination, timing of increased concentrations, and use of protective
28 equipment affect the risks of exposure at this node, and must be understood to determine if this
29 is a relevant impact category (per Section 7.4.2.2).

30
31 If human exposure to HIACs can be documented as a relevant impact category, the location of
32 exposures, unit process resulting in exposure, and human health endpoints which can result from
33 an exposure should also be understood and described in the LCA report, and in EPDs and C-EPDs
34 which are generated.

35
36 Emissions of certain HIACs can also result indirectly in risks of exposure by ingestion or dermal
37 contact, if the HIACs transfer to solid surfaces and skin. If midpoints and endpoints in the
38 stressor-effects network, and characterization model used, are distinct for the routes of indoor
39 inhalation, ingestion, and dermal contact, then category indicators in this impact category, and
40 for the impact category of Hazardous Food or Water Contaminant Exposure Risks, and the impact
41 category of Hazardous Dermal Contaminant Exposure Risks, will be relevant and should be
42 reported separately.

⁶² Meek, M.E., et al. *Risk assessment of combined exposure to multiple chemicals: A WHO/IPCS framework*. Regulatory Toxicology and Pharmacology 60 (2011) S1-S14.

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1 In rare instances, emissions contributing to ambient pollutant concentrations (i.e., ground level
2 ozone and/or particulate matter) will also contribute to concentrations of indoor pollutants, as
3 outdoor pollutants invade indoor spaces. In these cases, separate indicators should be reported
4 for relevant indicators representing ambient exposure risks (e.g., Ground Level Ozone Exposure
5 Risks, PM2.5 Exposure Risks) as well as for indicators in this impact category.
6

7 **7.4.2.1. Selection of Category Indicator(s).** After identifying all emissions of HIACs which
8 are relevant in this impact category according to Section 7.4.2.2, distinct category
9 indicators are defined.

10
11 To define these distinct category indicators, the stressor-effects network for emissions of
12 each HIAC should first be considered separately. Separate category indicators shall be
13 reported for each HIAC emitted under the following conditions:
14

- 15 • Midpoints in the stressor-effects network are distinct in the location of human
16 exposure, duration of exposures, severity of exposures over health thresholds, and
17 number of humans exposed.
- 18 • The mode of action and/or human health endpoints associated with inhalation of
19 each HIAC are distinct in their character, temporal duration, severity, persistence,
20 reversibility, or other considerations.
- 21 • The characterization model used to assess category indicator results is distinct.
22

23 Aggregation of emissions of different HIACs into a single category indicator is only possible if
24 there are consistent measures of inhalation toxicity available for use as the basis for PP-CFs.
25 If there is no scientific basis for aggregating multiple HIACs using PP-CFs (see Section 7.4.4.1),
26 multiple category indicators must be reported.
27

28 Ideally, the midpoint selected for the category indicator would be Node 3, representing the
29 contribution to the risk of exposure to HIACs in indoor environments which are in exceedance
30 of threshold. A characterization model is not established in this Standard for characterization
31 at Node 2 or higher nodes, due to a lack of data. Characterization at Node 1 is generally
32 recommended based on data which is available, measuring emissions levels in indoor
33 settings.
34

35 NOTE. This does not preclude the establishment of characterization models at Node 2 or
36 higher in specific LCA studies, quantifying actual risk of exposure in indoor environments.
37 If results are characterized at Node 2 or higher, the basis of data sources and modeling
38 must be described in the LCA report. The uncertainty in any data sources and models
39 must be considered. As characterization models become established and more broadly
40 available, these may be incorporated into future versions of this Standard.
41

42 Characterization at Node 1 (emissions of HIACs) has low environmental relevance. This low
43 environmental relevance shall be described in the LCA report, and wherever results are
44 reported.
45

46 In practice, there will be many cases where no data are available to characterize results at
47 any node, even when the contribution to human exposures to HIACs over health thresholds
48 is observed and documented at unit process(es) in the anthropogenic system. In these cases,
49 the reporting requirements described in Section 7.4.6 apply.

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1
2 **7.4.2.2. Identifying Core Impact Categories and Category Indicator(s).** Due to the
3 extensive data collection and analysis required to characterize category indicators for
4 HIAC Exposure Risks, it is essential to carefully screen the anthropogenic system
5 under study to identify the unit processes contributing to risks of human exposures
6 to HIACs in indoor environments which are in exceedance of threshold. This
7 screening minimizes the amount of data collection required.

8
9 NOTE. Although characterization takes place at Node 1, the determination of this impact
10 category as relevant is based on a screening of linkages to the midpoint at Node 3,
11 representing the risks of exposure to humans from inhalation in indoor settings.

12
13 This impact category should be considered relevant for a given HIAC emitted from a given
14 unit process, if the emission satisfies the following conditions:

- 15
- 16 • In indoor environments at the given unit process, the HIAC has been detected in air.
 - 17 • The indoor environment is in exceedance of threshold, according to the requirements
18 of Section 7.4.1.2 and 7.4.1.2.1.
 - 19 • Emissions of the HIAC are shown to contribute to contamination of indoor air at this
20 unit process.
 - 21 • Protective equipment is not used, or is not used sufficiently, to prevent exposures to
22 humans by inhalation.
- 23

24 These emissions can occur from many possible unit process(es) in the anthropogenic system.
25 However, indoor air emissions are not usually included in inventory datasets. Accordingly,
26 during the initial screening, it is important to identify types of unit processes that have been
27 known in other cases to have emissions that contribute measurably to human exposure to
28 HIACs. These unit processes may include, for instance, various stages of manufacturing, and
29 the use of specific product types.

30 **FOR EXAMPLE.** Carpets, flooring, furniture, and other products used indoors may
31 emit VOCs during their use, leading to risk of exposure to building occupants.

32
33
34 **FOR EXAMPLE.** In factories, emissions may occur as a result of the handling of
35 intermediate chemicals, which can volatilize and result in emissions to indoor air,
36 leading to elevated concentrations of HIACs. However, in many factory settings,
37 protective equipment is used (e.g., face masks) preventing or strictly limiting
38 potential human exposures. The regulatory setting and factory policies must be
39 carefully considered when assessing indoor exposure risks in factory settings.

40 **Note** Careful research must determine whether these emissions are occurring and leading to risks of
41 exposure, based on primary data sources.

42
43 In some cases, data may be unavailable to determine whether emissions at a given unit
44 process are contributing to the risk of exposures, even when secondary data or unverified
45 anecdotal information strongly indicate that such exposures are occurring. Only direct
46 observations can be used as a concrete basis for determination of the relevance of this impact
47 category. If it cannot be determined that an emission source leads to relevant impacts, the

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1 ability to achieve the goals of the study may be affected, and the goal and/or scope may need
2 revision.

3
4 When determining if HIAC Exposure Risks is a core impact category, the scale of the
5 functional unit used shall be large enough to include observed instances of midpoints of
6 contaminated indoor air over known health thresholds. The functional unit must not be set
7 arbitrarily low, which could rule out this impact category even in cases where HIAC Exposure
8 Risks are occurring and can be linked to emissions from the anthropogenic system. This
9 screening may require sensitivity analysis.

10
11 The initial screening for the relevance of this impact category may determine that the scale
12 of the functional unit needs revision, or that the goal and/or scope needs revision in other
13 ways.

14
15 The justification for the inclusion or exclusion of this impact category shall be provided in the
16 LCA report.

17
18 **7.4.2.2.1. Using Emissions Testing Data.** For products that may emit HIACs
19 during the use phase (e.g., furniture or flooring products used in indoor
20 environments), emissions testing can be used to help determine if this impact
21 category is relevant. Emissions testing results for a given product can be used as the
22 basis for determining if HIAC Exposure Risks is a relevant impact category. A
23 description of the emission testing protocol used shall be included in the LCA report.

24
25 **FOR EXAMPLE.** *The Standard Method for the Testing and Evaluation of Volatile*
26 *Organic Chemical Emissions from Indoor Sources Using Environmental Chambers*, the
27 emission testing method for the California Specification 01350, can be used as the
28 basis of such emissions testing.

29
30 In determining the relevance of the impact category, the emissions of specific HIACs must
31 be considered in the context of the indoor environment as a whole. A product may satisfy
32 requirements for an emissions testing protocol, and still contribute measurably to
33 instances of elevated concentrations of HIACs over health thresholds. In these cases, the
34 tested product emits an HIAC into an indoor environment in which concentrations of
35 HIACs are over health thresholds (see Section 7.4.1.2 and 7.4.1.2.1). In these cases, the
36 tested product contributes to these elevated concentrations, and emissions of the HIAC
37 will be relevant to this impact category.

38
39 **7.4.2.2.2. Using Concentration Testing Data.** For some unit processes, local
40 regulations mandate the testing of concentrations of certain substances in indoor
41 settings over certain time periods, and at certain intervals of time.

42
43 **FOR EXAMPLE.** In the United States, this can include regulations enforced by agencies
44 such as the Occupational Safety and Health Administration.

45
46 If data are available based on results of regulatory testing protocols, they can be used to
47 determine relevance of the impact category. In such cases, the timing of the most recent
48 testing and past history of infractions must be taken into account, and the local regulation,
49 and timing and characteristics of the tests conducted must be described in the LCA report.

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1
2 **7.4.3. Classification.** All emissions of HIACs which are relevant to this impact category per the
3 requirements of Section 7.4.2.2 are classified.

4
5 For some anthropogenic systems, it may not be possible to classify all HIACs contributing to this
6 impact category, as a result of data limitations. Based on the significance of the omission, the goal
7 and scope of the LCA study may need to be revised.

8
9 In addition, substances present in products used in an indoor setting, which have the potential to
10 contaminant indoor air and cause human health impacts, should be listed. This list should be
11 included in the LCA report and in EPDs and C-EPDs.

12
13 It should be clearly described in the LCA report, and in EPDs and C-EPDs, for which HIACs
14 exposure is concretely established, and for which substances exposure and health impacts cannot
15 be verified but could be occurring. This will aid in prioritization of which HIACs are of greatest
16 concern, and should be the target of projects intended to minimize exposures.

17
18
19
20
21
22 **7.4.4. Characterization**

23
24 **7.4.4.1. Potency Potential Characterization Factors.** The PP-CF is determined separately
25 by HIAC, and is separately defined for each category indicator included in the study scope
26 (see Section 7.4.2.1).

27
28 The PP-CFs is used to aggregate emissions of HIACs into indoor air into a single category
29 indicator, using the inhalation toxicity of each HIAC as an equivalency factor. This PP-CF can
30 be defined as this inhalation toxicity in relation to the inhalation toxicity of a reference
31 contaminant with similar human health endpoints. For each category indicator, the same
32 reference contaminant, and consistent measures of inhalation toxicity, must be used.

33
34 NOTE. For category indicators based on emissions of a single HIAC, the HIAC is its own
35 reference contaminant.

36
37 The PP-CF for this impact category can be calculated using Equation 7.8.

38
39 **Equation 7.8. Potency Potential Characterization Factor for HIAC Exposure Risks.**

$$S - CF_i = \frac{\text{inhalation toxicity}_i}{\text{inhalation toxicity}_{reference}}$$

Where:

- PP-CF is the Potency Potential Characterization Factor for a given HIAC, denoted *i*
- Inhalation toxicity is the measure of the inhalation toxicity for the given HIAC (denoted *i*), and the reference contaminant.

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1 NOTE. Emissions levels multiplied by the PP-CF defined using Equation 7.8 produces
2 results in units of equivalent mass of the reference contaminant. The PP-CF equation will
3 depend upon the units of the measures of inhalation toxicity.
4

5 For HIACs with toxic effects in humans which have a clear dose threshold for onset, the
6 inhalation toxicity can be characterized using the lowest inhalation exposure threshold
7 resulting in onset of the critical toxic effect. This is typically measured in milligrams / cubic
8 meter for daily inhalation exposure.
9

10 NOTE. Values of the chronic Reference Exposure Level (CREL) for chemicals, which are
11 reported by the State of California Office of Environmental Health Hazard Assessment,
12 can be used to characterize the PP-CF for HIACs and toxic effects that have a dose
13 threshold for onset.
14

15 NOTE. If a CREL is not available for an HIAC, the inhalation Reference Concentration
16 (RfC) can be used, which are reported in the US Environmental Protection Agency's
17 Integrated Risk Information System database.
18

19 However, for many HIACs, there is no clear dose threshold for onset of toxic effects. In these
20 cases, extreme care must be taken in defining the inhalation toxicity of different HIACs and
21 reference contaminants, in order to provide a defensible basis for aggregation for multiple
22 HIACs under a single category indicator.
23

24 **FOR EXAMPLE.** Carcinogenicity is a toxic effect that does not exhibit a clear threshold for
25 onset. PP-CFs for carcinogenicity must be represented by measures such as the Inhalation
26 Unit Risk.
27

28 If there is no scientifically defensible basis for assessing PP-CFs for multiple HIACs based on
29 consistent measures of inhalation toxicity, there is no way to aggregate emissions into a single
30 category indicator. In these cases, separate category indicators must be reported for each
31 HIAC which is emitted.
32

33 NOTE. The lack of a consistent basis for aggregation often indicates that the modes of
34 action and/or toxic endpoints of HIACs are different, and that the stressor-effects
35 networks are distinct.
36

37 When deriving PP-CFs, the uncertainty in the measure of inhalation toxicity should be
38 considered in the context of the goal and scope of the study. If the uncertainty in the PP-CFs
39 is very high, it may not be possible to achieve the goals of the LCA study. In these cases, the
40 goal and scope may need to be revised.
41

42 NOTE. For HIACs exhibiting toxic effects with a clear dose threshold based upon
43 inhalation, measures based on the onset of the critical toxic effect are the most widely
44 used, as these measures usually contain the least inherent uncertainty. However, even
45 these measures can contain inherent uncertainties of one order of magnitude or more.
46

47 The measures of inhalation toxicity used must be based upon empirical measurements from
48 peer-reviewed studies. Generic extrapolation between measures, such as the lowest onset

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1 threshold for the critical toxic effect and the median effective dose (ED50) value for a given
2 HIAC, shall not be used.

3
4 **7.4.4.2. Midpoint Characterization Factors.** For category indicators in this impact category,
5 characterization models for nodes higher than Node 1 have not been established (see Section
6 6.4.2). There is no M-CF for characterization at Node 1.

7
8 **7.4.5. Indicator Equation and Unit of Measure.** Results (at Node 1) can be calculated using
9 Equation 7.9. Results calculated using Equation 7.9 are in units of mass equivalents of the
10 reference contaminant.

11 *Equation 7.9. Indicator equation for a single unit process for HIAC Exposure Risks. Results calculated*
12 *using this equation are at Node 1, characterizing emissions of HIACs.*

$$\text{HIAC Emissions} = \sum_i (\text{Emissions}_i \times \text{PP-CF}_i)$$

Where:

- *Emissions_i are the emissions levels of a given HIAC, reported in units of mass.*
- *PP-CF_i is the Potency Potential Characterization Factor for each HIAC, representing its inhalation toxicity relative to the reference contaminant.*

14
15 **7.4.6. Additional Reporting Requirements.** In some instances, data on emission levels will be
16 unavailable for a given unit process, even though specific emissions of HIACs are known to
17 contribute to impacts in this impact category. Under such circumstances, characterization of
18 indicator results is not possible. In these cases, the relevant category indicator shall be noted as
19 relevant, and the location of emissions, type of emissions, and HIACs contributing to elevated
20 concentrations in indoor air over health thresholds, shall be described in the LCA report, and
21 any EPDs and C-EPDs which are generated.

22
23 The stressor-effects network should be described in the LCA report. The specific midpoint of
24 contaminated indoor air to which an emission can be linked must be described in the LCA report,
25 and EPDs and C-EPDs which are generated. Endpoints of human health effects resulting from
26 exposures to the relevant HIACs should also be included in the description.

27
28 **7.4.7. Addressing Additional Limitations in Types, Accuracy, and Availability of**
29 **Environmental Data.** In some cases, no data will exist to determine the inhalation toxicity or
30 maximum safe ambient air concentration of HIACs which are emitted by unit processes in the
31 anthropogenic system, and which have been detected in indoor air. In these cases, it may not be
32 possible to determine if emissions of the HIAC could be linked to human health impacts, and it
33 will not be possible to aggregate these emissions using PP-CFs. In these cases, the effect on final
34 results should be considered, and documented as a limitation in the LCA report. Emissions of
35 these HIACs should be documented in the LCA report. If the HIAC emissions from given unit
36 processes are significant, and contribute to indoor environments where concentrations of the
37 HIAC are problematic, it may not be possible to achieve the goals of the study. The goal and
38 scope of the LCA study may need to be revised.

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1 **7.5. Ingestion Exposures to Hazardous Chemicals**

2
3 **7.5.1. Impact Category.** This impact category considers releases of hazardous food or water
4 contaminants (HFWCs) from unit process(es) in the anthropogenic system that can result in risks
5 of human exposure through ingestion. The potential routes of human exposure by ingestion
6 usually include the contamination of drinking water or food supply (e.g., agricultural products,
7 ocean going fish).
8

9 The emissions most relevant to this impact category are contaminants with long residence times
10 in the environment, which can bioaccumulate in organisms and the human body, and/or are
11 chemically mobile. These chemicals can result in chronic human exposures, which will usually
12 only occur after transport through multiple media, and may occur years after an emission occurs.
13

14 NOTE. In some instances, emissions may occur which result in acute human exposures in the
15 short term. In practice, such acute exposures occur in rare instances.
16

17 The severity, spatial scale, and reversibility of risks of human exposure through ingestion will
18 vary broadly, depending on factors such as the HFWC emitted, scale of emission, timing of
19 emission, duration of emission, medium of emission, and regional setting. The midpoints and
20 endpoints associated with this impact category vary for all of these reasons. Accordingly, site-
21 specific assessment of HFWC Exposure Risks associated with a unit process is required.
22 Secondary data shall not be used in the assessment of this impact category.
23

24 **7.5.1.1. Definition of Hazardous Food or Water Contaminants.** For this impact category,
25 HFWCs are those contaminants which have the potential to expose humans via ingestion of food
26 or water, and which have been observed to cause adverse effects if humans are exposed to oral
27 doses over health thresholds.
28

29 At the outset of the study, the set of HFWCs considered should be clearly defined. The set of
30 HFWCs should include those which have exposed humans in the past from ingestion of food or
31 water at concentrations over health thresholds. This includes contaminants which have been
32 detected in ground or surface water supplies, or in food sources such as leafy crops, root crops,
33 meat, dairy products, fish or seafood.
34

35 In practice, the set of HFWCs will be limited to a small number of persistent and/or
36 bioaccumulative chemicals, which are also mobile.

37 NOTE. Due to its persistence and mobility, mercury contamination is an issue at regional and global levels.
38 Mercury should be included in the initial set of HFWCs.
39

40 For a given LCA study, the set of HFWCs will be screened to identify those emission sources which
41 are relevant for HFWC Exposure Risks (see Section 7.5.2.2).
42

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1 **7.5.1.2. Definition of Threshold Exceedance for HFWC Exposure Risks.** For a given HFWC,
2 the health threshold is a concentration, defined separately in food and water, usually expressed
3 in units such as mg/kg, µg/kg, or ppb. A food of water supply is defined as being in exceedance
4 of threshold if the HFWC has been detected at levels over this health threshold. If emissions of
5 an HFWC are found to be relevant in this impact category based on the requirements of Section
6 7.5.2.2, the health threshold used, and basis of the threshold, shall be described in the LCA
7 report.

8
9 The health threshold for a given HFWC is the maximum safe concentration of the HFWC in
10 drinking water or food supplies, below which there is no known or expected risk to health, with
11 oral ingestion on a daily basis over a lifetime.

12
13 Whenever possible, the health threshold for an HFWC should be based upon published estimates
14 of the maximum safe concentration in food or water. For contamination of drinking water
15 supplies, Maximum Contaminant Level Goals (MCLGs) are provided for many HFWCs by the US
16 EPA; MCLGs are estimates of the level of a contaminant in drinking water below which there is
17 no known or expected risk to health. If available, the MCLG can be used to define the health
18 threshold for a given HFWC if it is a water contaminant.⁶³ For contamination of food supplies,
19 maximum allowed levels in food defined by government agencies can be used as the basis of
20 defining the health threshold for an HFWC.

21 **For example.** The European Commission has defined maximum levels in food for children of several heavy
22 metals and organic substances, which could be used as the basis of the health threshold for these HFWCs.

23 **For example.** The US EPA has established tolerances (also known as residue limits) for pesticides in foods.
24 These residue limits can be used as the basis of a health threshold for pesticides.

25
26 If published estimates of the maximum safe concentration do not exist for an HFWC, the health
27 threshold must be estimated. To establish the health threshold for given HFWC in food or water,
28 the dose of the HFWC must be considered to which a person can be exposed to on a daily basis
29 over an extended period of time (usually a lifetime) without suffering adverse effects. For an
30 HFWC, this dose can be established based upon the Reference Dose for Chronic Oral Exposure
31 (RfD), established by the US EPA, or similar measures, such as the Acceptable Daily Intake (ADI).
32 The health threshold of a specific HFWC is based upon the safe daily dose and expected
33 consumption of the HFWC.

34 **Note.** RfDs and ADIs are based upon the NOAEL, LOAEL, or benchmark dose for a given HFWC. If an RfD or
35 ADI is not available for a given HFWC, the health threshold must be based upon a NOAEL, LOAEL, or
36 benchmark dose. The uncertainty in these measures related to human exposures should be considered.
37 Conservative assumptions shall be made to account for uncertainty in NOAEL, LOAELs, and benchmark
38 concentrations.

39
40 For some HFWCs, the onset of adverse effects after exposure may occur at levels which are so
41 low they cannot be defined. In these cases, the health threshold can be defined operationally as
42 the lowest concentration in food or water at which the HFWC can be detected on a routine basis.

⁶³ US EPA. *Drinking Water Contaminants*. <http://water.epa.gov/drink/contaminants/#List>

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1
2
3 **7.5.2. Stressor-Effects Network.** The stressor-effects network for this impact category depends
4 upon the size, location, timing, duration, and nature, of an emission; the resulting scale, severity,
5 and reversibility of midpoints of contaminated food/water supplies will vary for many reasons.
6

7 The stressor-effects network for this impact category, shown in Table 7. 5 in Annex B, provides a
8 general framework. However, for each separate indicator included within the study scope, a
9 separate stressor-effects network shall be modeled. This model should describe the site-specific
10 stressors, midpoints, and endpoints in the cause-effect relationship linked to each classified
11 emission source which is considered. This will greatly aid in the characterization of results.
12

13 The midpoint of contaminated food and water supplies (Node 4) is directly linked to the risk of
14 human exposure. For contaminated food and water supplies, the contaminants, spatial scale,
15 persistence, and level of contamination should be understood. Contaminated food and water
16 supplies may be linked to emissions occurring at one or more unit processes considered in the
17 anthropogenic system under study, but may also be linked with unit processes outside of the
18 scope of the LCA. Accordingly, it is important to understand other emissions sources that are
19 contributing to these midpoints.
20

21 If HFWC Exposure Risks can be documented as a relevant impact category (Section 7.5.2.2), the
22 human health endpoints that can result from an exposure should be understood and described
23 in the LCA report, and in any EPD and C-EPD which is generated.
24

25 The emissions which are relevant to this impact category may also be linked to stressor-effects
26 networks for ecotoxicity, since the midpoint at Node 3 (persistent contamination of the receiving
27 environment) is similar.
28

29 **7.5.2.1. Selection of Category Indicator(s).** After identifying all emissions of HFWCs which
30 are relevant in this impact category according to the requirements of Section 7.5.2.2, distinct
31 category indicators are defined.
32

33 To define these distinct category indicators, the stressor-effects network for each HFWC
34 emission should first be considered separately. Separate category indicators shall be
35 reported for each HFWC emitted under the following conditions:
36

- 37 • Midpoints in the stressor-effects network linked to the emission are distinct in spatial
38 extent, duration, severity of contamination, and number of humans that could be
39 exposed.
- 40 • The route of exposure to humans is distinct.
- 41 • Modes of action and/or human health endpoints associated with ingestion of the
42 HFWC are distinct in character, temporal duration, severity, persistence, reversibility,
43 or other aspects.
- 44 • The characterization model used to assess category indicator results is distinct.
45

46 Aggregation of emissions of different HFWCs into a single category indicator must be done
47 with care; even emissions that occur at similar levels, at the same place and time, may lead to
48 distinct cause-effects chains.

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1
2 **FOR EXAMPLE.** Heavy metals, such as mercury, have significantly different chemical
3 half-lives, mobility in the environment, and toxic effects compared to organic chemicals.
4 Even if mercury and an organic chemical are co-emitted, the distinct nature of the
5 persistence, mobility, and risk of human exposures means that it may not be possible to
6 aggregate emissions of mercury and organic chemicals into a single category indicator.

7
8 Aggregation of HFWCs into the same category indicator is only possible if there are consistent
9 measures of oral toxicity available for use to establish PP-CFs. If there is no scientific basis for
10 aggregation of multiple HFWCS using PP-CFs, multiple category indicators must be reported.

11
12 Ideally, the midpoint selected to characterize HFWC Exposure Risks would be Node 4,
13 representing the fraction of an emission contributing to the contamination of a food/water
14 supply in which HFWCs are at concentrations over safe health thresholds. In practice, there
15 is rarely sufficient data available to characterize results at Node 4. Therefore,
16 characterization at Node 3 should be used if possible – i.e., the fraction of an emission
17 contributing to persistent contamination of the receiving environment, irrespective of
18 whether food/water supplies are contaminated.

19
20 However, in most instances, data will only be available for characterization at Node 1.
21 Characterization at Node 1 has low environmental relevance. This low environmental
22 relevance shall be described in the LCA report.

23
24 The stressor-effects network should be described in the LCA report. The contaminated
25 food/water supply to which an emission can be linked must be described in the LCA report,
26 and in EPDs and C-EPDs which are generated. Endpoints of human health effects resulting
27 from exposures to the relevant chemicals should also be included.

28
29 **7.5.2.2. Identifying Core Impact Categories and Category Indicator(s).** Due to the
30 extensive data collection and analysis required to characterize category indicators for this
31 impact category, it is essential to carefully screen the anthropogenic system under study to
32 identify the unit processes that are contributing to risks of human exposure to HFWCs over
33 defined health thresholds. This screening should minimize the amount of data collection
34 required.

35
36 NOTE. Although for a given study, characterization may be at Node 1, the determination
37 of this impact category as relevant is based on a screening of linkages to the midpoint at
38 Node 4, representing the risk of exposure to humans from ingestion of food/water where
39 HFWCs are present over defined health thresholds.

40
41 HFWC Exposure Risks should be considered relevant for a given HFWC emitted from a given
42 unit process, if the emission satisfies two conditions:

- 43
44
- 45 • The HFWC has been detected as a contaminant in a specific water supply used for
46 drinking (ground or surface water), or in a specific source of food for humans (e.g.,
47 leafy crops, root crops, meat, dairy products, fish, or seafood from oceans and lakes).
48 The concentration of the HFWC should occur at levels exceeding the defined health
49 threshold for the medium that is contaminated. The health threshold is defined by
HFWC, according to the requirements of Section 7.5.2.1.

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- The emission must be shown to contribute to contamination of the specific water supply or food source.

As part of the iterative process, those unit process(es) in the anthropogenic system that result in significant emissions of HFWCs should be identified; it can then be determined if these emissions are occurring in regions where the HFWC in question occurs in food/water supplies at concentrations over the defined health threshold. This type of monitoring data is often readily available from governmental monitoring programs or in published literature.

An alternative approach is to identify regions considered in the study where a HFWC occurs in food/water supplies at concentrations over safe thresholds, and determine if any emission sources in the study scope could contribute.

If a unit process has been determined to exist in a region where food/water supplies are in exceedance of threshold, and the unit process has associated emissions of the HFWC, the emission still must be linked to the increased concentration of that HFWC. In establishing the linkage, the persistence and bioaccumulative properties of the HFWC emitted by a unit process should be considered. Measures of the persistence of a chemical species should consider its chemical half-life or elimination time in different media (e.g., soil, sediments, water); and measures of its bioaccumulative properties, such as the bioconcentration or bioaccumulation factor.

NOTE. An HFWC can be considered to be persistent if one of the following conditions exists: its water solubility is > 3 ppm (mg/L), its soil adsorption coefficient (K_{oc}) is < 1,900 cm^3/g , its hydrolysis half-life is > 14 days, its aerobic soil metabolism half-life is > 610 days, or its anaerobic soil metabolism half-life is > 9 days.

NOTE. An HFWC can be considered to be bioaccumulative if: its bioconcentration factor or bioaccumulation factor has been shown to be > 500 in the tissues of humans, fish, wildlife, or plants, in any environmental media, in any research; or if $\log K_{ow}$ of a substance is ≥ 4 .

When conducting this screening, it is important to identify types of unit processes that have been known in the other cases to have emissions that contribute measurably to risks of exposure to humans via ingestion. This can include consideration of: unit processes by type, when similar unit processes are known to emit substances that cause contamination of food or water supplies; the chemical species and region of emission, if the species is a widespread contaminant in food or water supplies where the unit process is located; or the regulatory setting in which a unit process is located, if emissions controls in the region where it is located are lax.

FOR EXAMPLE. Coal-fired power plants emit trace amounts of mercury, though the level of mercury emitted depends on the assay of coal used and emission controls in place. Electricity generation derived from coal-fired sources should be investigated, to determine if resulting mercury emissions are contributing to contamination of food or water supplies in the region.

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1 Unit process(es) located in regions where contamination of food or water supplies is an issue
2 of concern to regional government agencies and or other stakeholders should also be
3 identified.

4
5 **FOR EXAMPLE.** Contamination of sediments in the Great Lakes region of North America
6 has been addressed by legislation in both the United States and Canada. The US EPA has
7 a program devoted to assessment and remediation of contaminated sediments.
8 Contamination of food and water supplies in this region are an issue, particularly
9 resulting from methylmercury contamination of fish. Emissions contributing to regional
10 instances of contamination in the Great Lakes region should be considered for relevance
11 in this impact category.

12
13 In some cases, the most significant emissions of HFWCs will occur far “upstream” in the
14 anthropogenic system under study. These significant emission sources often occur in small
15 unit operations in regions which are not subject to emission controls. A thorough screening
16 of the available literature can help to determine if such unit processes exist in the
17 anthropogenic system under study. Contamination of food and water supplies is often well-
18 researched even in countries with lax emission controls, and data will usually be available to
19 link a unit process to these active midpoints.

20
21 Care should be taken to ensure that this impact category is not mistakenly identified as
22 relevant. HFWC Exposure Risks can be ruled out as a relevant impact category if there are no
23 unit process(es) in the anthropogenic system that contribute measurably to the risk of
24 exposure to humans to HFWCs by ingestion of food or water where concentration of HFWCs
25 are over defined health thresholds. For a given HFWC emitted from a given unit process, the
26 following guidance can be used to exclude this impact category as relevant:

- 27
28
- 29 • If there are no contaminated food or water supplies in which the HFWC occurs over
30 the defined health threshold, in regions to which the HFWC could transport
(considering its persistence in the environment);
 - 31 • If the HFWC has very low transport potential, and even if present in the environment,
32 cannot pose a risk to human exposures through ingestion;
 - 33 • If the HFWC has a very short elimination time in the environment into which it is
34 emitted, and has no possibility of transporting to cause contamination of food or
35 water supplies before it is removed from the environment through chemical
36 decomposition or other processes.

37
38 The justification for the inclusion or exclusion of this impact category shall be provided in the
39 LCA report.

40
41 Whether this impact category is included as relevant to a anthropogenic system depends on
42 the goal and scope of the LCA study. When screening to determine if HFWC Exposure Risks is
43 a core impact category, the scale of the functional unit used shall be large enough to include
44 observed instances of midpoints of contaminated food or water supplies. The functional unit
45 should be scaled based upon the gross scale of emission levels in the anthropogenic system.
46 The functional unit must not be set arbitrarily low, which could rule out this impact category
47 even in cases where HFWC exposure risks are occurring and can be linked to emissions from
48 a unit process in the anthropogenic system. This screening may require sensitivity analysis.

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1 NOTE. If specific data is unavailable for gross emissions, gross emissions can be estimated using
2 conservative assumptions. This impact category is not relevant if emission levels of HFWCs are negligible,
3 even when considering the gross scale of emissions estimated using conservative assumptions.
4

5 An initial screening for the relevance of this impact category may determine that the scale of
6 the functional unit, or the goal and scope, needs revision. The exclusion of this as a core
7 impact category should be a key subject of the critical review phase.

8 NOTE. While the number of HFWCs emitted from all unit processes in an anthropogenic system can
9 be large, in practice, very few emissions will be of a nature and scale such that risks of human
10 exposure from ingestion will result. In addition, in most regions, very few HFWCs are present
11 above known health thresholds in food or water supplies. The screening for HFWC Exposure Risks
12 should be able to quickly determine if this impact category is relevant to unit processes in the
13 anthropogenic system. An efficient screening will require expert judgment and sensitivity analysis
14 to guide the iterative process.
15

16
17 **7.5.1.2.1. Relevance of Product Material Composition.** In some cases, a product in use
18 may include, as part of its physical composition, an HFWC. In such cases, there must be a
19 route of exposure of ingestion to humans during the use phase to warrant inclusion of
20 this impact category as relevant. In many cases, such products have no possible way to
21 expose humans via ingestion.
22

23 **FOR EXAMPLE.** An office chair is known to contain lead, a HFWC, as part of its material
24 composition. However, this lead is present as a trace material in the chair's aluminum
25 components; it is chemically inert and bonded in the aluminum's crystal structure.
26 There is no possible mechanism by which this lead could expose humans by ingestion.
27 The presence of lead in the office chair does not warrant inclusion of HFWC Exposure
28 Risks as relevant for this anthropogenic system.
29

30 Conversely, a product may contain only inert chemicals as part of its physical
31 composition, and yet contribute to active midpoints of food or water supply
32 contamination during its production. This highlights the need for a thorough screening of
33 the anthropogenic system to identify contributors to HFWC Exposure Risks, irrespective
34 of the product's material composition.
35

36 **FOR EXAMPLE.** Finished polyurethane foam is itself a chemically inert product that
37 does not contain materials that are significantly toxic. However, polyurethane foam
38 is sometimes produced using a precursor chemical called toluene diisocyanate (TDI);
39 effects of TDI exposure can include primary irritation, sensitization (e.g., "isocyanate
40 asthma"), and progressive impairment of lung function as a result of long-term
41 exposures.⁶⁴ Although TDI is not present in finished polyurethane foam, in some
42 industries, TDI use has been poorly regulated, and there have been documented
43 instances of worker exposure and resulting toxic effects through inadvertent TDI

⁶⁴ US Environmental Protection Agency, Integrated Risk Information System. 2,4-/2,6- Toluene diisocyanate mixture (TDI) (CASRN 26471-62-5)

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1 ingestion.⁶⁵ Although in this case, the finished product has no hazardous material
2 constituents, HFWC Exposure Risks could be a relevant impact category if TDI is used
3 in its production.
4

5
6 **7.5.3. Classification.** All emissions of HFWCs which meet the requirements of a Section 7.5.2.2
7 shall be classified. Different HFWCs may be classified into separate category indicators.
8

9 **7.5.4. Characterization**

10
11 **7.5.4.1. Potency Potential Characterization Factors.** The PP-CF is determined by HFWC,
12 and is separately defined for each category indicator included in the study scope. In cases
13 where multiple HFWCs are considered in a single category indicator, the PP-CF characterizes
14 the oral toxicity of each HFWC compared to the oral toxicity of a reference contaminant with
15 similar human health endpoints. For each category indicator, the same reference
16 contaminant, and consistent measures of oral toxicity, must be used.
17

18 NOTE. For category indicators that include emissions of a single HFWC, the HFWC is its
19 own reference contaminant.
20

21
22
23
24
25 The PP-CF for this impact category is shown in Equation 7.10.
26

27 **Equation 7.10. Potency Potential Characterization Factor for HFWC Exposure Risks.**

$$S - CF_i = \frac{\text{oral toxicity}_i}{\text{oral toxicity}_{\text{reference}}}$$

Where:

- PP-CF is the Potency Potential Characterization Factor for a given HFWC, denoted *i*
- Oral toxicity is the measure of the oral toxicity for the given HFWC (denoted *i*), and the reference contaminant.

28
29 NOTE. Results of emissions levels multiplied by the PP-CF shall give results in units of
30 equivalent mass of the reference contaminant. The PP-CF equation will thus depend upon
31 the units of the measures of oral toxicity that are used.
32

33 For HFWCs with toxic effects in humans which have a clear dose threshold for onset, the oral
34 toxicity of the HFWC can be characterized using the lowest oral exposure threshold resulting
35 in onset of the critical toxic effect, typically measured in mg_{dose} / kg_{body}-day.
36

⁶⁵ Los Angeles Times, 7/27/2006, by Jennifer Delson. *Widow of Worker Sues Foam Factory.*

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1 NOTE. The Reference Dose for Chronic Oral Exposure (RfD) for an HFWC, from the US
2 EPA's Integrated Risk Information System database, can be used to characterize the PP-
3 CF for HFWCs which have toxic effects with a clear dose threshold for onset.
4

5 However, for many HFWCS, there is no clear dose threshold for onset. In these cases, extreme
6 care must be taken in defining the oral toxicity of different HFWCs and the reference
7 contaminant, in order to provide a defensible basis of aggregation for multiple HFWCs
8 included in a single category indicator.
9

10 **FOR EXAMPLE.** Carcinogenicity is a toxic effect that does not exhibit a clear dose
11 threshold for onset. PP-CFs for carcinogenicity must be represented by measures such as
12 the Oral Slope Factor.
13

14 **FOR EXAMPLE.** Although inorganic lead is a substance which can induce toxic effects
15 which are similar to those induced by other heavy metals, there is no dose threshold for
16 the toxic effects of lead. Current observations indicate that any exposure to lead can lead
17 to toxic effects; certain effects can result from such low levels of lead concentrations in
18 the bloodstream that there is essentially no threshold.⁶⁶ This means it is not possible to
19 establish oral toxicity based on a dose threshold for inorganic lead, since no such dose
20 threshold exists.
21

22 If there is no scientifically defensible basis for assessing PP-CFs for multiple HFWCs based on
23 consistent measures of oral toxicity, there is no way to aggregate emissions into a single
24 category indicator. In these cases, separate category indicators must be reported for each
25 emission.
26

27 NOTE. The lack of a consistent basis for aggregation often indicates that the modes of
28 action and/or toxic endpoints of HFWCs are different, and that the stressor-effects
29 networks are distinct.
30

31 For HFWCs exhibiting toxic effects with a clear dose threshold, measures based on the onset
32 of the critical toxic effect are the most widely used, as these measures usually contain the
33 least inherent uncertainty. However, even these measures can contain inherent uncertainties
34 of one order of magnitude or more. When deriving PP-CFs, the uncertainty in the measure of
35 oral toxicity should be considered in the context of the goal and scope of the study. If the
36 uncertainty levels in the PP-CFs which are calculated are very high, it may not be possible to
37 achieve the goal(s) of the study. In such cases, the goal and scope may need to be revised.
38

39 The oral toxicity measures used must be based upon empirical measurements from peer-
40 reviewed studies. Generic extrapolation between measures such as the lowest onset
41 threshold for the critical toxic effect and the median effective dose (ED50) value for a given
42 chemical species shall not be used.
43

⁶⁶ US EPA, Integrated Risk Information System summary. *I.A.1: Oral RfD Summary: Lead and compounds (inorganic)*.

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1 **7.5.4.2. Midpoint Characterization Factors.** For category indicators in this impact category,
2 three levels of reporting at three different nodes are possible, based upon data availability
3 (see Section 7.5.2. and Table 7.6):
4

- 5 • Node 4, Characterizing the fraction of a HFWC emission that contributes to the
6 contamination of a food or water supply in exceedance of threshold according to
7 Section 6.5.1.2.
- 8 • Node 3, Characterizing the fraction of a HFWC emission that contributes to the
9 persistent contamination of the receiving environment (not considering
10 contamination of any food/water supplies, or the defined health threshold).
- 11 • Node 1, Characterizing the emission level of relevant HFWCs.
12

13 For a single category indicator, the same characterization model must be applied to all
14 emissions of all HFWCs from all relevant unit processes. Comparison between results
15 calculated using different characterization models is not possible. In LCA reports, the
16 category indicator selected and characterization model used to derive results must be
17 described.
18

19 The characterization models used for assessment at each node are described in the sections
20 below.
21

22 **7.5.4.2.1. Characterization of Contribution to Food or Water Supply Contamination.**

23 The M-CF assesses the fraction of a HFWC emission that contributes to contamination of
24 a food or water supply in exceedance of threshold. At Node 4, the characterization model
25 used is the most environmentally relevant measure that is possible. However, the
26 characterization must integrate modeling of the fate, transport, and accumulation of each
27 HFWC emitted, and will typically require significant modeling resources to complete.
28

29 The uncertainty inherent in the modeling of fate and transport of HFWCs throughout the
30 receiving environment shall be considered when characterizing results for this indicator.
31 Uncertainty levels should be included where results are reported, preferably as a
32 confidence interval. The model uncertainty may be significant enough that the goal of the
33 LCA study cannot be achieved. In these cases, the goal and scope may need to be revised,
34 or the characterization of results must be at a lower node which has less associated
35 uncertainty.
36

37 NOTE. For the emissions of certain HFWCs, the risk of human exposure occurs after
38 extensive transport, long after the emission occurs. In these cases, modeling of fate
39 and transport may not be possible due to the very high uncertainties associated with
40 this modeling.
41

42 The severity, spatial scale, and reversibility of food and water supply contamination
43 associated with different emissions from different unit processes will vary broadly,
44 depending on factors such as the HFWC emitted, scale of emission, timing of emission,
45 duration of emission, medium of emission, and regional setting. Associated midpoints and
46 endpoints vary for all of these reasons. Accordingly, site-specific assessment at this node
47 is required. Secondary data shall not be used in the characterization.
48

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1 **7.5.4.1.2. Characterization of Contribution to Receiving Environment**
2 **Contamination.** The M-CF assesses the fraction of a HFWC emission that contributes to
3 persistent contamination of the receiving environment, irrespective of contamination of
4 food or water supplies, or whether the food or water supply is in exceedance of threshold.
5 The characterization must integrate modeling of the fate, transport, and accumulation of
6 each HFWC that is emitted. It must consider the persistence of the HFWC in the receiving
7 environment into which it is emitted.
8

9 The uncertainty inherent in the modeling of fate and transport of chemicals throughout
10 the receiving environment shall be considered when characterizing results for this
11 indicator. Uncertainty levels should be included where results are reported, preferably
12 as a confidence interval. The modeling uncertainty may be significant enough that the
13 goal of the LCA study cannot be achieved. In these cases, the goal and scope may need to
14 be revised, or the characterization of results must be at Node 1.
15

16 The severity, spatial scale, and reversibility of persistent receiving environment
17 contamination associated with different emissions from different unit processes will vary
18 broadly, depending on factors such as the HFWC emitted, scale of emission, timing of
19 emission, duration of emission, medium of emission, and regional setting. Associated
20 midpoints and endpoints vary for all of these reasons. Accordingly, site-specific
21 assessment at this node is required. Secondary data shall not be used in the
22 characterization.
23

24 **7.5.4.1.3. Characterization of Emissions Levels.** At Node 1, indicator results assessed
25 have no M-CF. Emissions contributing to a category indicator are assessed strictly as
26 emissions levels, and do not integrate fate and transport.
27

28 **7.5.5. Indicator Equation and Unit of Measure.** For results reported at Node 4, the indicator
29 equation is shown in Equation 7.11; for results at Node 3, the indicator equation is shown in
30 Equation 7.12; for results reported at Node 1, the indicator equation is shown Equation 7.13.
31 Regardless of the node of characterization, results are reported in units of mass equivalents of
32 the reference contaminant.
33

34 **Equation 7.11. Indicator equation for a single unit process for HFWC Exposure Risks, with results reported**
35 **at Node 4 (contribution to contamination of food or water supplies).**

$$\text{HFWC Exposure Risks} = \sum_i (\text{Emissions}_i \times \text{PP-CF}_i \times \text{M-CF})$$

Where:

- *Emissions_i are the emission levels of a given HFWC, reported in units of mass.*
- *PP-CF_i is the Potency Potential Characterization Factor for each HFWC, representing its oral toxicity relative to the reference contaminant.*
- *M-CF is the Midpoint Characterization Factor, which characterizes the fraction of the emission that contributes to the contamination of a specific food/water supply in exceedance of threshold.*

36
37 **Equation 7.12. Indicator equation for a single unit process for HFWC Persistent Contamination, with**
38 **results reported at Node 3 (contribution to persistent contamination of the receiving environment).**
39

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$$\text{HFWC Persistent Contamination} = \sum_i (\text{Emissions}_i \times \text{PP-CF}_i \times \text{M-CF})$$

Where:

- *Emissions_i are the emission levels of a given HFWC, reported in units of mass.*
- *PP-CF_i is the Potency Potential Characterization Factor for each HFWC, representing its oral toxicity relative to the reference contaminant.*
- *M-CF is the Midpoint Characterization Factor, which characterizes the fraction of the emission that contributes to the persistent contamination of the receiving environment.*

1
2 **Equation 7.13. Indicator equation for a single unit process for HFWC Emissions, with results reported at**
3 **Node 1 (emissions levels).**

$$\text{HFWC Emissions} = \sum_i (\text{Emissions}_i \times \text{PP-CF}_i)$$

Where:

- *Emissions_i are the emission levels of a given HFWC, reported in units of mass.*
- *PP-CF_i is the Potency Potential Characterization Factor for each HFWC, representing its oral toxicity relative to the reference contaminant.*

4
5 **7.5.6. Additional Reporting Requirements.** In the LCA report, and EPDs and C-EPDs which
6 are generated, the midpoint of contaminated food or water supplies associated with a category
7 indicator shall be described, along with the toxic endpoints that can result from human intake
8 of the relevant HFWC.
9

10 The category indicator name which is used shall clearly describe the modeling used, and not
11 overstate the environmental relevance of results.
12

13 **7.5.7. Addressing Additional Limitations in Types, Accuracy, and Availability of**
14 **Environmental Data.** The first step in characterization of results in this impact category is the
15 screening for determination of relevance of emissions of HFWCs, according to the requirements
16 and guidance provided in Section 7.5.2. In some anthropogenic systems, where unit processes in
17 the anthropogenic system are distributed in extensive global supply chains, lax regulations and
18 poor monitoring might make it impossible to determine the relevance of specific emission
19 sources to this impact category. If the screening cannot be conducted, then determination of the
20 relevance of this impact category is not possible; this could affect the ability to achieve the goals
21 of the LCA study. If the relevance of this impact category cannot be determined, the goal and scope
22 of the LCA study may need to be revised.
23

24 In certain cases, although the scale of emission from a unit process may be unknown, the nature
25 and region of an emission occurring in the anthropogenic system under study will be understood,
26 and there will be observational data clearly showing that the emission contributes to the active
27 midpoint of contamination of a food or water supply. In these cases, the HFWC emitted and
28 region of emission shall be reported as a separate indicator, with the midpoints and endpoints
29 described, although results cannot be assessed.
30

31 **FOR EXAMPLE.** The mining of certain materials, including mercury and arsenic, in countries
32 such as China, has been observed to contribute to regional instances of contamination of food

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1 and/or water supplies from heavy metals.^{67,68,69} However, inventory data will typically be
2 unavailable to characterize emissions of these heavy metals resulting from mining in these
3 regions, which often occurs in unit processes that are very far upstream. Although inventory
4 data may be unavailable, it must be reported in the LCA report, and in EPDs and C-EPDs, that
5 emissions of HFWCs are occurring from mining in this region.
6

7 In some cases, no data will exist to determine the oral toxicity or maximum safe concentration of
8 HFWCs in food or water which are emitted by unit processes in the anthropogenic system, and which
9 have been detected in food or water supplies at elevated concentrations. In these cases, it may not be
10 possible to determine if emissions of the HFWC could be linked to human health impacts, and it will
11 not be possible to aggregate these emissions using PP-CFs. In these cases, the effect on final results
12 should be considered, and documented as a limitation in the LCA report. Emissions of these HFWCs
13 should be documented in the LCA report. If the HFWC emissions from given unit processes are
14 significant, and contribute to food and/or water supplies where concentrations of the HFWC are
15 problematic, it may not be possible to achieve the goals of the study. The goal and scope of the LCA
16 study may need to be revised.
17

18 **7.6. Dermal Contaminant Exposure Risks**

19
20 **7.6.1. Impact Category.** This impact category considers releases of hazardous dermal
21 contaminants (HDCs) from unit process(es) in the anthropogenic system that can result in risks
22 of human exposure through dermal contact and absorption through the skin. Human exposure
23 through dermal contact can result from air emissions (either in ambient or indoor settings) which
24 transfer to skin, or use of hazardous chemicals in a fashion which results in direct contact with
25 skin. After initial contact, these chemicals can also transfer to others by skin-to-skin contact.
26

27 The severity, spatial scale, and reversibility of risks of human exposure through dermal contact
28 will vary broadly, depending on factors such as the type and amount of HDC used or emitted in a
29 given instance, timing of use or emission, use of protective safety equipment, and other factors.
30 The midpoints and endpoints associated with this impact category vary for all of these reasons.
31 Accordingly, site-specific assessment of HDC Exposure Risks associated with a unit process is
32 required. Secondary data shall not be used in the assessment of this impact category.
33

34 **7.6.1.1. Definition of Hazardous Dermal Contaminants.** HDCs are those contaminants which
35 have the potential to expose humans via dermal contact, and which have been observed to
36 cause adverse effects if humans can absorb unsafe doses of the chemical in their skin.
37

38 At the outset of the study, specific research into instances where humans are exposed via dermal
39 contact to HDCs, with potential for unsafe doses being absorbed, should be researched. The set
40 of HDCs should focus on specific unit processes which are known to contribute to Dermal
41 Contaminant Exposure Risks.

⁶⁷ Zhu, Y.G., et al. *High Percentage Inorganic Arsenic Content of Mining Impacted and Nonimpacted Chinese Rice*. Environ. Sci. Technol., 2008, 42 (13), pp 5008-5013.

⁶⁸ P., Li, et al. *Mercury pollution in Wuchuan mercury mining area, Guizhou, Southwestern China: the impacts from large scale and artisanal mercury mining*. Environ Int. 2012 Jul;42:59-6

⁶⁹ Feng, X. et al. *Mercury pollution in Guizhou, Southwestern China—an overview*. Science of the Total Environment. Volume 400, Issues 1-3, August 2008, 227-237.

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1 FOR EXAMPLE. During many types of forestry and agriculture, herbicides are applied by backpack sprayers
2 to control the spread of non-desirable vegetative species. These herbicides can come in contact with the
3 skin of workers, and subsequently be absorbed into the bloodstream. The most important exposure route
4 is the absorption through the skin of the hands and forearms. After exposure, these herbicides can
5 subsequently enter the bloodstream. Exposure to 2,4-D and triclopyr through skin absorption are
6 documented in forest workers.^{70,71}

7
8
9 **7.6.1.2. Definition of Threshold Exceedance for HDC Exposure Risks.** For HDCs, clear health
10 thresholds are not as readily available as for the other routes of exposure. The safe threshold of
11 exposure for this impact category shall be based upon quantitative measures such as the
12 average daily dose (ADD), considering exposure through the skin. The health threshold can also
13 be based upon the NOAEL or LOAEL, or benchmark doses.

14
15 Alternatively, for a given type of unit process, direct evidence that a HDC exposes humans
16 through skin contact and causes toxic effects in a given instance can be used to demonstrate that
17 this impact category is relevant. Conservative assumptions shall be made to account for
18 uncertainty in NOAEL, LOAELs, and benchmark concentrations.

19
20 **7.6.2. Stressor-Effects Network.** The stressor-effects network for this impact category depends
21 upon the size, location, timing, duration, and nature, of an emission or use of a chemical; the
22 resulting scale, severity, and reversibility of human health impacts will vary for many reasons.

23
24 The stressor-effects network for this impact category, shown in Table 7. 6 in Annex B, provides a
25 general framework. However, for each separate indicator included within the study scope, a
26 separate stressor-effects network shall be modeled. This model should describe the site-specific
27 stressors, midpoints, and endpoints in the cause-effect relationship linked to each HDC. This will
28 greatly aid in the characterization of results.

29
30 If HDC Exposure Risks can be documented as a relevant impact category (Section 7.6.2.2), the
31 human health endpoints that can result from an exposure should be understood and described
32 in the LCA report, and in any EPD and C-EPD which is generated.

33
34 **7.6.2.1. Selection of Category Indicator(s).** After identifying all emissions of HDCs which
35 are relevant in this impact category according to the requirements of Section 7.6.2.2, distinct
36 category indicators are defined.

37
38 To define these distinct category indicators, the stressor-effects network for each HDC
39 emission shall be considered separately. Separate category indicators shall be reported for
40 each HDC emitted under the following conditions:

- 41
42
- The route of exposure to human skin is distinct.

⁷⁰ Dost, Frank N. *Toxicology and Potential Health Risk of Chemicals that May Be Encountered by Workers using Forest Vegetation Management Options. Part II: Exposure to and absorption of herbicides used in forestry.* British Columbia Ministry of Forests: Forest Practices Branch.

⁷¹ Zhang, X., et al. *Concurrent 2,4-D and triclopyr biomonitoring of backpack applicators, mixer/loader and field supervisor in forestry.* Journal of Environmental Sciences and Health part B (2011) 46, 281-293.

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- The spatial extent, duration, severity of contamination, and number of humans that could be exposed, is distinct.
- Modes of action and/or human health endpoints associated with the absorption into the bloodstream of the HDC are distinct in character, considering endpoint characteristics such as temporal duration, severity, persistence, reversibility, or other aspects.
- The characterization model used to assess category indicator results is distinct.

Aggregation of emissions of different HDCs into a single category indicator must be done with care; even emissions and/or use that occurs at similar levels, at the same place and time, may lead to distinct cause-effects chains.

FOR EXAMPLE. Applications of different herbicides, which can expose workers, can lead to different toxic effects. Exposure to 2,4-D at unsafe levels can lead to acute health impacts toxicity, cancer, and endocrine disruption, while exposure to glyphosate generally will result only in acute toxicity.

Aggregation of HDCs into the same category indicator is only possible if there are consistent measures of dermal toxicity available for use to establish PP-CFs. If there is no scientific basis for aggregation of multiple HDCS using PP-CFs, multiple category indicators must be reported.

In most instances, data will only be available for characterization at Node 1, characterization of emissions and/or use of HDCs. Characterization at Node 1 has low environmental relevance. This low environmental relevance shall be described in the LCA report.

The stressor-effects network should be described in the LCA report. The route of exposure to the skin shall be described I the LCD report, and in EPDs and C-EPDs which are generated. Endpoints of human health effects resulting from exposures to the relevant chemicals should also be included.

7.6.2.2. Identifying Core Impact Categories and Category Indicator(s). Careful screening is required to determine the relevance of HDC Exposure Risks. This screening should minimize the amount of data collection required.

HDC Exposure Risks should be considered relevant for a given unit process, if the emission satisfies two conditions:

- The HDC has been observed to pose a risk of exposure via dermal contact through emission or use. The exposure should have been documented as occurring at levels exceeding safe doses, or be observed in the bloodstream of affected humans. The determination of relevance of this impact category is defined by HDC.
- The emission or use in a given instance at a unit process must be shown to contribute to a risk of exposure via dermal contact.

To determine relevance of this impact category, it is important to identify types of unit processes that have been known in the other cases to have emissions or use that contributes measurably to risks of exposure to humans via dermal contact. This can include consideration of: unit processes by type, when exposure via dermal contact at similar unit processes is

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1 known to occur; or the regulatory setting in which a unit process is located, if worker safety
2 regulations in the region where it is located are lax.

3
4 When determining if HDC Exposure Risks is a core impact category, the scale of the functional
5 unit used shall be large enough to include observed instances of midpoints of humans
6 exposed via dermal contact. The functional unit should be scaled based upon the gross scale
7 of emission levels in the anthropogenic system. The functional unit must not be set arbitrarily
8 low, which could rule out this impact category even in cases where HDC exposure risks are
9 occurring. This may require sensitivity analysis.

10
11 **7.6.3. Classification.** All emissions of HDCs which contribute to risks of exposure via dermal
12 contact are included based on the requirements of Section 7.6.2.2. Different HDCs may be
13 classified into separate category indicators.

14
15 **7.6.4. Characterization**

16
17 Due to the widely varying nature of the stressor-effects network related to this impact category,
18 the characterization model to be used shall be defined for each instance uniquely, based upon the
19 route of contamination, severity of health impacts, and data which is available for
20 characterization. The characterization model used shall be described in the ELCA report.