Lubricants Life Cycle Assessment and Carbon Footprinting—Methodology and Best Practice

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Foreword

This document is classified as a Technical Report. API's *Procedures for Standards Development* define technical reports as documents that convey technical information on a specific subject or topic, are generally issued on a one time-basis, and are not standards.

This publication has been developed by industry subject matter experts established by the API Lubricants Standards Committee ("the Committee") with the original intention of producing a Standard. However, as development of this document proceeded, it was determined that the level of importance to industry of the accumulated information and references contained herein warranted early publication in the form of a Technical Report.

The Committee continues their effort to produce a Standard in a subsequent revision or replacement. Suggested revisions are invited and should be submitted to the Standards Department, API, 200 Massachusetts Avenue, Suite 1100, Washington, DC 20001, standards@api.org.

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1 Introduction and Scope

Life cycle assessment (LCA) and carbon footprints of products (CFP) are established methodologies used to quantify the environmental performance of products, processes, or services, and are increasingly being used as a basis for environmental decision-making along the supply chain. While LCA includes multiple impact categories, CFP focuses specifically on the impact category of "climate change", which is associated with greenhouse gas (GHG) emissions/removals.

Both LCA [1, 2] and CFP [6] depend on functional methods for which there are international standards that set principles, requirements, and guidelines for carrying out such studies. Despite these standards, choices are still left with the practitioner performing the study, regarding, for example: setting the boundaries of the system; allocation of impacts between co-products or recycled products; selecting metrics used to estimate impacts; and choosing the sources of data. These choices can have significant impacts on the outcome of a performed assessment, and alignment on these choices is needed to allow for fair comparison of results from different studies.

This need for alignment is the motivation to create a common LCA and CFP framework for lubricant products within the API Lubricants Sustainability Group. This collaboration was formed through the cooperation of API members with the intention of providing guidance via this technical report (TR).

The purpose of this document is to define terminology and to identify and capture best practices for LCA and CFP of lubricants [1] (see Figure 1). The overall aim is to promote harmonization and consistency in the application of LCA and CFP across the lubricants industry. While many concepts discussed in this technical report will be generally applicable to both LCA and CFP assessments, more detailed discussion in this version of the document is often focused on CFP assessments; this is driven by strong interest from the industry in the topic.

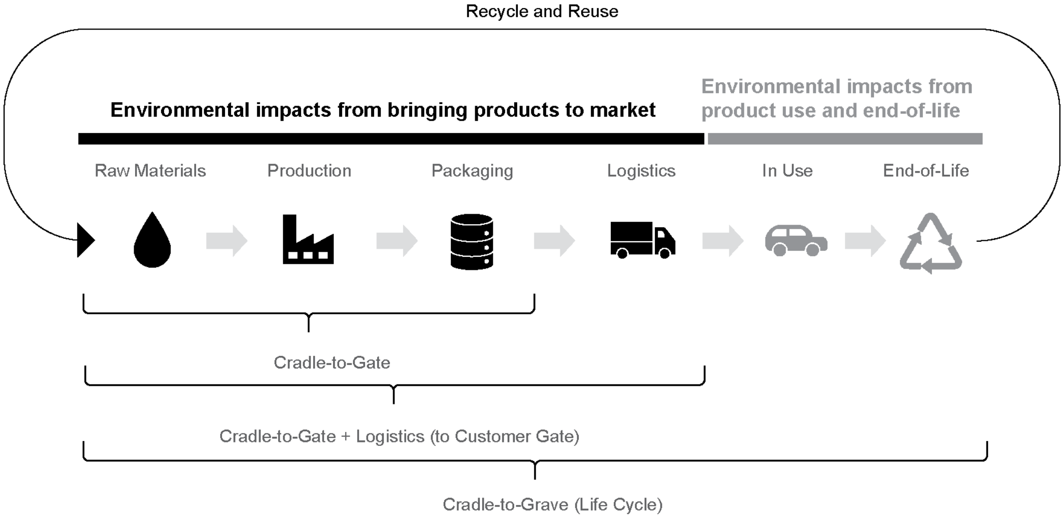

Figure 1—Overview of the Key Stages of the Lubricant Life Cycle

This best-practice document is not intended to be as prescriptive and detailed as product category rules (PCR). However, it could serve as the foundation for such definitions at a later date.

Lubricants for various application areas, that are consistent with the definition of a "lubricant" as provided in 3.1 and where sufficient data are available to describe the life cycle stages outlined in Figure 1, are part of the scope

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[1] "Lubricant" is defined in 3.1. For the purposes of this technical report, the term encompasses "lubricants and specialty products."

for this technical report. The applicability of the methodology in this document to a specific case in hand can ultimately be decided by the practitioner executing the study. Examples of lubricants include but are not limited to the following:

— engine oils (both light and heavy duty);

— driveline fluids;

— greases;

— other industrial-type fluids, e.g. thermal management, hydraulic fluids, gear oils.

This technical report defines the CFP for a lubricant product on a life cycle (Figure 1) or cradle-to-grave basis. Therefore, to generate the CFP, the absolute GHG emission and removals at each stage of the life cycle are summed up (Figure 2) and converted to CO_2 equivalent (CO_2e). To generate a partial CFP, e.g. on a cradle-to-gate basis, the respective, absolute GHG emissions and removals at the applicable life cycle stages are summed up and converted to CO_2e.

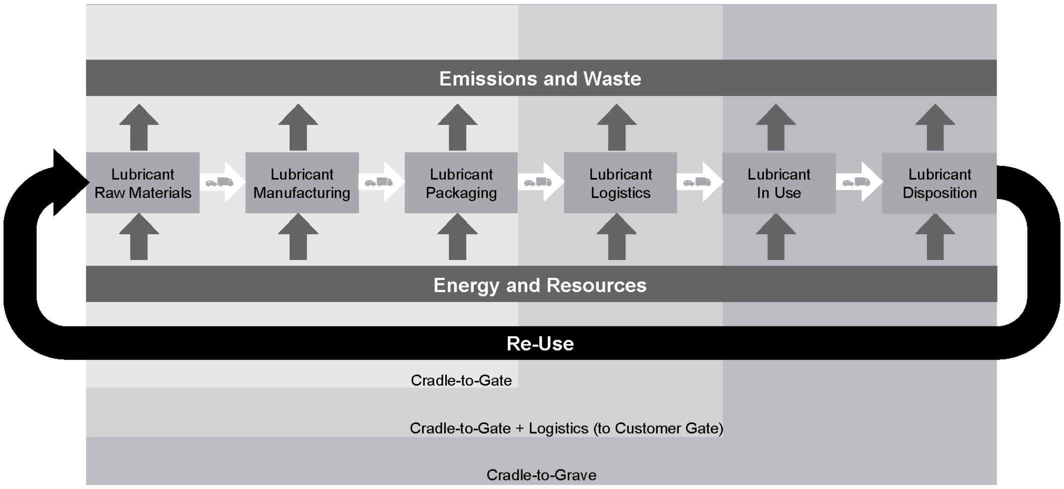

Figure 2—Definition of Scopes for Carbon Footprint of Product (CFP) Assessments

With the focus on the carbon content of the lubricant itself, Figure 3 examines in more detail the potential losses of the lubricant to the environment after the production (after cradle-to-gate + logistics) and until final disposition. These potential losses should be accounted for and included in the assessment if a cradle-to-grave scope of the CFP is intended to be covered.

This technical report provides general methodological recommendations in Section 4, while more detailed considerations along the stages of the life cycle are covered in Section 5. The life cycle stages falling into the cradle-to-gate + logistics scope are covered in 5.1 through 5.4. To complete the cradle-to-grave scope, 5.5 and 5.6 cover the “in use” and “end-of-life” life cycle stages, respectively, in more detail.

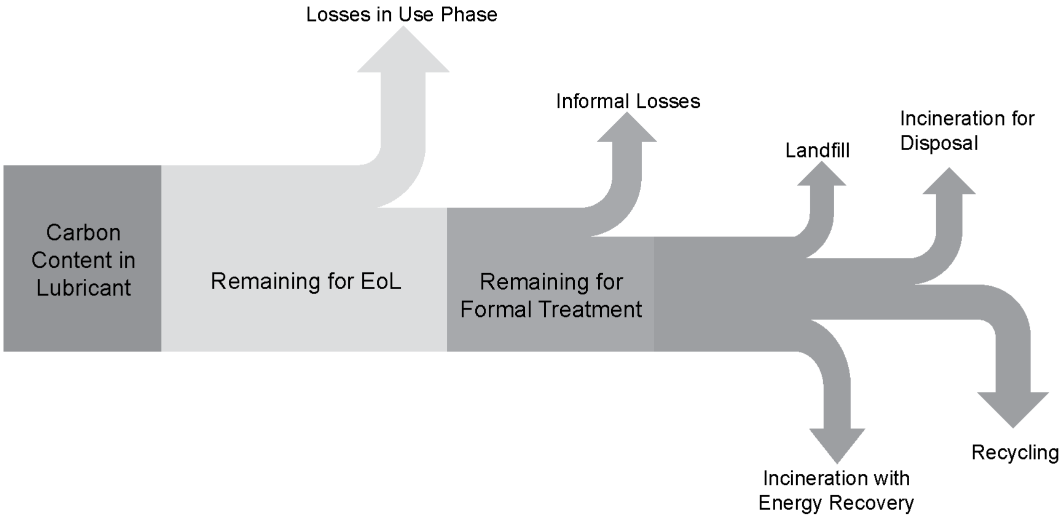

Figure 3—Tracing Carbon Content through the "In Use" and "End-of-Life" Stages of the Life Cycle

While the cradle-to-grave scope includes losses in the "in use" stage (e.g. partial combustion of lubricant during use), certain "in use benefits" should stand separately, in addition to the carbon footprint (CFP). "In use benefits", also referred to as "avoided emissions" or "comparative emissions", rely on a relative comparison between two scenarios, one where the product exists and one where it is replaced by a reference product or functionally relevant baseline [19]. "Avoided emissions" are discussed briefly in Section 6 of this technical report and could involve calculations that assess the following:

— avoided emissions from extension of the oil drain interval (ODI), thereby reducing the volume of lubricant required across the lifetime of the application;

— avoided emissions during the use of the lubricant product, through fuel economy due to efficiency improvements, thereby reducing the volume of fuel required to travel a certain distance or operate for a certain period of time.

Such calculations of avoided emissions are of strong industry interest but are also complex matters. Future updates to this technical report may include a more comprehensive treatment of these topics.

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 14040,[2] *Environmental management — Life cycle assessment — Principles and framework*

ISO 14044, *Environmental management — Life cycle assessment — Requirements and guidelines*

ISO 14067, *Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantificatio*

ISO 14021, *Environmental labels and declarations — Self-declared environmental claims (Type II environmental labelling)*

ISO 14071, *Environmental management — Life cycle assessment — Critical review processes and reviewer competencies: Additional requirements and guidelines to ISO 14044:2006*

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[2] International Organization for Standardization, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, www.iso.org.

WRI Greenhouse Gas Protocol,[3] *Product Life Cycle Accounting and Reporting Standard*

BSI PAS 2050,[4] *Specification for the assessment of the life cycle greenhouse gas emissions of goods and services*

3 Terms, Definitions, Acronyms, and Abbreviations

3.1 Terms and Definitions

For the purposes of this document, the following terms and definitions apply.

3.1.1

additive package

A combination of additive components that provide targeted lubricant performance.

NOTE Further information on additives can be found in 5.1.2.

3.1.2

avoided emissions

Based on a relative comparison between two scenarios—one where the product exists and one where it is replaced by a reference/functionally equivalent baseline product—it can be shown that the former leads to reduced emissions.

[adapted from World Resources Institute, *Estimating And Reporting The Comparative Emissions Impacts Of Products,* 2019]

NOTE High-level discussion on the topic of “avoided emissions” is provided in Section 6.

3.1.3

biogenic carbon

“Carbon derived from biomass”.

[Source: ISO 14067:2018, Section 3.1.7.2]

NOTE For biogenic carbon in lubricants, see 4.8.

3.1.4

biomass

“Material of biological origin, excluding material embedded in geological formations and material transformed to fossilized material”.

[Source: ISO 14067:2018, Section 3.1.7.1]

“NOTE 1 Biomass includes organic material (both living and dead), e.g. trees, crops, grasses, tree litter, algae, animals, manure, and waste of biological origin”.

“NOTE 2 In this document, biomass excludes peat”.

3.1.5

blends

Mixes of different components designed to meet a specific ratio in composition.

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[3] World Resources Institute, 10 G Street, NE, Suite 800, Washington, DC 20002, www.ghgprotocol.org.

[4] British Standards Institution, 389 Chiswick High Road, London W4 4AL United Kingdom, www.bsigroup.com.

3.1.6
carbon content

Carbon (both fossil and biogenic carbon) contained in the molecules that make up the lubricant product.

3.1.7
carbon dioxide equivalent (CO_2e)

“A unit for comparing the radiative forcing of a GHG to that of carbon dioxide”.

[Source: ISO 14067:2018, Section 3.1.2.2]

NOTE For a lubricant, the mass of applicable GHGs is converted into CO_2 equivalents by multiplying the mass of the GHG by the corresponding global warming potential over a 100-year time frame (GWP-100).

3.1.8
carbon footprint of a product (CFP)

“The sum of GHG emissions and GHG removals in a product system, expressed as CO_2 equivalents and based on a life cycle assessment using the single-impact category of climate change”.

[Source: ISO 14067:2018, Section 3.1.1.1]

NOTE 1 A definition of a carbon footprint for a lubricant on a cradle-to-grave basis is provided in Section 1.

NOTE 2 In line with ISO 14067:2018, Section 3.1.1.7, carbon offsetting is not allowed in the quantification of a CFP or a partial CFP.

3.1.9
carbon neutral

“Carbon neutral refers to a product (as a product system) that has a CFP of zero or a product for which the emissions determined as the CFP have been reduced to zero through offsetting”.

“In relation to a product, carbon neutral requires that all the GHG emissions from all stages of the product life cycle, and within the specified product system, have been reduced, removed or accounted for through a system of offsetting or credits, or by other means”.

[Source: ISO 14021:2016 + Amd 1:2021, Sections 7.17.3.1 and 7.17.3.2]

3.1.10
circular economy

“A model of production and consumption that involves sharing, leasing, reusing, repairing, refurbishing, and recycling existing materials and products as long as possible”.

[Source: Bibliography Reference [9]]

3.1.11
cradle-to-gate

All upstream stages until the production gate. This includes the following life cycle stages: raw materials, production, and packaging (if applicable).

NOTE For “cradle-to-gate + logistics,” the logistics to the customer gate is added to the scope of the above definition of cradle-to-gate.

3.1.12
cradle-to-grave

All stages of the lubricant life cycle (Figure 1) are included in this scope, typically covering the following: raw materials, production, packaging, logistics, in use, and end-of-life.

3.1.13
comparative assertion
"An environmental claim regarding the superiority or equivalence of one product versus a competing product that performs the same function".

[Source: ISO 14044:2006, Section 3.6]

3.1.14
comparative emissions
A difference in emissions based on a relative comparison between two scenarios: one where the product exists and one where it is replaced by a reference/functionally relevant baseline product.

NOTE A high-level discussion on the topic is provided in Section 6.

3.1.15
components
Different constituent parts (e.g. base oil and additives) from which a lubricant is blended.

3.1.16
critical review
"A process intended to ensure consistency between a life cycle assessment and the principles and requirements of international standards on life cycle assessment".

[Source: ISO 14044:2006, Section 3.45]

"NOTE 1 The principles are described in ISO 14040:2006, Section 4.1".

"NOTE 2 The requirements are described in ISO 14044:2006, Section 6".

3.1.17
cut-off criteria
"Specification of the amount of material or energy flow or the level of environmental significance associated with unit processes or product systems to be excluded from a study".

[Source: ISO 14044:2006, Section 3.18]

NOTE Information on cut-off criteria as they pertain to lubricants can be found in 4.5.

3.1.18
direct land use change (dLUC)
"A change in the human use of land within the relevant boundary".

[Source: ISO 14067:2018, Section 3.1.7.5]

"NOTE 1 In this document, the relevant boundary is the boundary of the system under study".

"NOTE 2 Land use change happens when there is a change in the "land-use category" as defined by the IPCC (e.g. from forest land to cropland)".

3.1.19
embedded carbon
See "carbon content".

3.1.20
end-of-life
The final stage in the life cycle of a product.

3.1.21
environmental impact
“A change to the environment, whether adverse or beneficial, wholly or partially resulting from an organization’s environmental aspects”.

[Source ISO 14001:2015, Section 3.2.4]

3.1.22
environmental aspect
“An element of an organization’s activities or products or services that interacts or can interact with the environment”.

[Source ISO 14001:2015, Section 3.2.2]

“NOTE 1 An environmental aspect can cause (an) environmental impact(s). A significant environmental aspect is one that has or can have one or more significant environmental impact(s)”.

“NOTE 2 Significant environmental aspects are determined by the organization applying one or more criteria”.

3.1.23
feedstock
Raw materials entering a process of refinement or synthesis step.

NOTE For lubricants, examples could be a used lubricant entering a re-refinement process or naphtha being converted via synthesis to an additive component.

3.1.24
fuel economy
A coefficient relating distance traveled by a vehicle with the amount of fuel consumed.

3.1.25
global warming potential (GWP)
“An index based on the radiative properties of GHGs that measures the radiative forcing following a pulse emission of a unit mass of a given GHG in the present-day atmosphere integrated over a chosen time horizon, relative to that of carbon dioxide (CO_2)”.

[Source: ISO 14067:2018, Section 3.1.2.4]

NOTE For calculating CFPs for lubricants, the GWPs over 100-year horizon (GWP-100), as published by the IPCC, should be used for conversions of the impacts of other GHGs to CO_2 equivalent.

3.1.26
greenhouse gas (GHG)
“A gaseous constituent of the atmosphere, both natural and anthropogenic, that absorbs and emits radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth’s surface, the atmosphere, and clouds”.

[Source: ISO 14067:2018, Section 3.1.2.1]

NOTE 1 For a lubricant, at a minimum, the following GHGs should be considered: CO_2, CH_4, and N_2O. For a list of GHGs, see the latest IPCC Assessment Report [10].

“NOTE 2 Water vapor and ozone, which are anthropogenic, as well as natural GHGs, are not included in the CFP and partial CFP”.

“NOTE 3 The focus of this document is limited to long-lived GHGs; therefore, it excludes climate effects due to changes in surface reflectivity (albedo) and short-lived radiative forcing agents (e.g. black carbon and aerosols)”.

3.1.27
greenhouse gas emissions

“Releases of GHG into the atmosphere”.

[Source: ISO 14067:2018, Section 3.1.2.5]

3.1.28
greenhouse gas emission factor

“A coefficient relating activity data with the GHG emission”.

[Source: ISO 14067:2018, Section 3.1.2.7]

3.1.29
greenhouse gas (GHG) removal

“The withdrawal of GHG from the atmosphere”.

[Source: ISO 14067:2018, Section 3.1.2.6]

3.1.30
indirect land use change (iLUC)

“A change in the use of land that is a consequence of direct land use change, but that occurs outside the relevant boundary”.

[Source: ISO 14067:2018, Section 3.1.7.6]

“NOTE 1 In this document, the relevant boundary is the boundary of the system under study”.

“NOTE 2 Land use change happens when there is a change in the “land-use category” as defined by the IPCC (e.g. from forest land to cropland)”.

3.1.31
informal losses

Used oil entering informal treatment channels (e.g. used oil available for collection but not arriving in formal treatment channels).

NOTE Further details on formal and informal used oil treatment can be found in 5.6.1.

3.1.32
life cycle assessment (LCA)

“The compilation and evaluation of the inputs, outputs, and the potential environmental impacts of a product system throughout its life cycle”.

[Source: ISO 14067:2018, Section 3.1.4.3]

3.1.33
lubricant

“A product that is capable of reducing friction, adhesion, heat, wear, or corrosion when applied to a surface or introduced between two surfaces in relative motion or is capable of transmitting mechanical power”.

[Source: Bibliography Reference [11]]

3.1.34
non-energy product

A product that is not intended to be combusted for energy production.

NOTE It is acknowledged that, in two stroke applications, the lubricant will inevitably be combusted, but this is not its main intended function.

3.1.35
oil drain interval

The interval between the instances when most of the lubricant in an application is changed. This can be measured in distance (e.g. kilometers or miles) or time (e.g. hours of operation).

3.1.36
partial carbon footprint of a product

“The sum of GHG emissions and GHG removals of one or more selected process(es) in a product system, expressed as CO_2 equivalents and based on the selected stages or processes within the life cycle”.

[Source: ISO 14067:2018, Section 3.1.1.2]

NOTE An example of a partial carbon footprint of a lubricant would be a cradle-to-gate footprint.

3.1.37
primary data

“The quantified value of a process or an activity obtained from a direct measurement or a calculation based on direct measurements”.

[Source: ISO 14067:2018, Section 3.1.6.1]

“NOTE 1 Primary data need not originate from the product system under study because primary data might relate to a different but comparable product system to that being studied”.

“NOTE 2 Primary data can include GHG emission factors and/or GHG activity data (defined in ISO 14064-1:2006, Section 2.11)”.

NOTE 3 For further details on data sources for lubricants, see 4.6.

3.1.38
raw materials

“Primary or secondary material that is used to produce a product”.

[Source: ISO 14044:2006, Section 3.15]

“NOTE Secondary material includes recycled material”.

3.1.39
re-refined base oil

Lubricant base stock derived in part or completely from used oil via refinery processes.

3.1.40
Scope 1 emissions

“Direct GHG emissions occur from sources that are owned or controlled by the company; for example, emissions from combustion in owned or controlled boilers, furnaces, vehicles, etc., or emissions from chemical production in owned or controlled process equipment”.

[Source: Bibliography Reference [28]]

3.1.41
Scope 2 emissions

“GHG emissions from the generation of purchased electricity consumed by the company. Purchased electricity is defined as electricity that is purchased or otherwise brought into the organizational boundary of the company. Scope 2 emissions physically occur at the facility where electricity is generated”.

[Source: Bibliography Reference [28]]

NOTE Scope 2 emissions as used in this technical report also include imported steam.

3.1.42

secondary data

"Data that do not fulfil the requirements for primary data".

[Source: ISO 14067:2018, Section 3.1.6.3]

NOTE For further details on data sources, see 4.6.

3.1.43

sensitivity analysis

"Systematic procedures for estimating the effects of the choices made regarding methods and data on the outcome of a study".

[Source: ISO 14044:2006, Section 3.31]

3.1.44

value chain

A series of consecutive steps that are needed to create a finished product. At each step of the chain, value is added.

3.2 Acronyms and Abbreviations

For the purposes of this document, the following acronyms and abbreviations apply.

API	American Petroleum Institute
ATIEL	Technical Association of the European Lubricants Industry
BO	base oil
CC	complete combustion (all embedded carbon released as CO_2)
CD	combustion for disposal
CFP	carbon footprint of product
CHP	combined heat and power
CHR	combustion with heat recovery
DEFRA	Department for Environment, Food and Rural Affairs
dLUC	direct land use change
EF	emission factor
EoL	end-of-life
EPA	Environmental Protection Agency
GHG	greenhouse gas
GLEC	Global Logistics Emissions Council
GWP	global warming potential
HDPE	high-density polyethylene
IBC	intermediate bulk containers
ICCA	International Council of Chemical Associations
iLUC	indirect land use change
IPCC	Intergovernmental Panel for Climate Change

LCA	life cycle assessment
LCIA	life cycle impact assessment
LBP	lubricant blend plant
MF	mass fraction
ODI	oil drain interval
PAS	publicly available standard
REDII	Renewable Energy Directive
RRBO	re-refined base oil
TR	technical report
TfS	Together for Sustainability
USDA	U.S. Department of Agriculture
VGO	vacuum gas oil
WBCSD	World Business Council for Sustainable Development
WRI	World Resource Institute
WtW	well-to-wheel
Wt%	weight percent

4 Methodology Recommendations for LCA of Lubricants

4.1 Goal of the Assessment

The overall goal of the application of this technical report to the life cycle assessment (LCA) of lubricants is to promote that a common methodology is applied across industry when, for example, defining the carbon footprint of product (CFP) for the lubricant in question. It will outline industry best practice, where the selected international standard allows for methodological choices to be made.

The following international standards and industry guidelines are applicable in this technical report:

International standards:

— ISO 14040:2006, *Environmental management — Life cycle assessment — Principles and framework*

— ISO 14044:2006, *Environmental management — Life cycle assessment — Requirements and guidelines*

— ISO 14067:2018, *Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantificatio*

Industry guidelines and national standards:

— GHG Protocol, *Product Life Cycle Accounting and Reporting Standard*

— PAS 2050:2011, *Specification for the assessment of the life cycle greenhouse gas emissions of goods and services*

The focus of this technical report is on the definition of the CFP and therefore addresses “climate change” as a single-impact category. There is an acknowledgment that focus and optimization of a single-impact category can lead to greater impacts in other environmental aspects. Such trade-offs can be identified and the LCA expanded with additional impact categories, where applicable, to obtain a more complete picture of the overall environmental impact of the product.

Output from calculations according to the above standards and performed in accordance with the best practice defined in this technical report could be used to demonstrate carbon neutrality according to the standard listed below.[5] Further specifications on demonstration of carbon neutrality are detailed in the standard below, and this application is beyond the scope of this technical report:

- PAS 2060:2014, *Specification for the demonstration of carbon neutralit*

4.2 Functional and Declared Unit

In line with Section 4.2.3.2 of ISO 14044:2006, the functional or declared unit defines the quantification of the identified functions (performance characteristics) of the product. A functional or declared unit will always be required as it provides a reference to which all inputs and outputs of the analyzed system are related. Based on the functional or declared unit, the associated reference flow is determined.

The functional or declared unit for lubricants according to this technical report is the performance characteristic relative to its mass (per kg of lubricant) or volume (per liter/U.S. gallon of lubricant). The latter unit is of interest, as lubricants are often sold on a volumetric basis. Using the product-specific density, the two units can be readily interconverted.

The examples below show the recommendations for the functional and declared unit in the application to a CFP or partial CFP assessment:

- Example 1: The functional unit for a CFP is the life cycle GHG emissions of a lubricant (expressed in CO_2 equivalent) relative to the lubricant mass:
  - Functional unit: cradle-to-grave emissions in kg CO_2e/kg of lubricant
- Example 2: For partial CFPs (e.g. for an intermediate material sold on cradle-to-gate basis), the declared unit is the GHG emissions (expressed in CO_2 equivalent), included according to the applicable scope and expressed relative to the lubricant mass.
  - Declared unit: cradle-to-gate emissions in kg CO_2e/kg of lubricant

While the above provides the recommendations for the functional and declared units for lubricants, the final choice of unit employed will depend on the goal and scope of the study. For some studies, it may be determined that the functional or declared unit is more appropriately determined based on, for example, the lifetime of the engine or a certain distance traveled. Similarly, it is acknowledged that for other applications (e.g. avoided emissions from extension in lubricant lifetime), like the ones discussed in Section 6 of this technical report, other units might be more applicable (e.g. number of years in a specific lubricant use profile or the amount of work performed, such as amount of metal processed). These could be reached via conversions from the functional units and declared units outlined above.

4.3 System Boundary

To determine the environmental impacts of a lubricant, all relevant stages of the lubricant life cycle shall be included in the assessment. An overview of the life cycle stages applicable to a generic lubricant are shown in Figure 1 and contain the six main life cycle stages: raw materials, production, packaging, logistics, in use, and end-of-life.

While the illustration in Figure 1 shows a primarily linear progression through the life cycle stages toward the end-of-life stage, characteristics of the circular economy are becoming increasingly important. For example, re-refined base oils (RRBO) are shown as a waste product from the end-of-life stage feeding back into the “raw material” stage of the life cycle.

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[5] Currently in preparation: ISO 14068, *Greenhouse gas management and related activities — Carbon neutrality*

An overview of the life cycle stages applicable to lubricant production is shown in Figure 1. Applicable system boundaries can be drawn according to the following scopes:

— Cradle-to-grave: All stages of the lubricant life cycle are included in this scope, and this represents the basis of the definition of the functional unit (4.2).

— Cradle-to-gate + logistics (to customer gate): All upstream stages of the lubricant life cycle until the customer entrance gate is reached. This includes logistics from the lubricant producer to the customer.

— Cradle-to-gate: All upstream stages of the lubricant life cycle until the production exit gate is reached. This excludes logistics of the lubricant to the respective customer.

NOTE Other scopes can also be defined (e.g. gate-to-gate). If such scopes are selected, these should be clearly defined as part of the documentation to ensure that it is transparent what is included in the system boundary.

In line with Section 6.3.4.1 of ISO 14067:2018, exclusions from the scope as defined by the system boundary—e.g. by exclusion of certain life cycle stages—shall be clearly stated and the reason for such exclusions explained. Such exclusions should be justified in accordance with the materiality threshold; e.g. as defined in the cut-off criteria (see 4.5 for details). Transparency in the documentation of the system boundary and possible exclusions is of crucial importance. This ensures that the user of the assessment has knowledge of the exact scope and environmental impacts considered to determine how the assessment meets their need for information.

It is common that activities not directly related to the production of a lubricant are seen as outside the scope, such as capital goods/installations and other non-production related overhead, cleaning, and research and development.

More detailed considerations of the system boundary, where applicable—e.g. application of the cut-off approach for certain used lubricant fates during the End-of-Life stage—are included in Section 5 of this document.

4.4 Allocation Approaches

As defined in Section 4.3.4.2 of ISO 14044:2006 and Section 6.4.6.2 of ISO14067:2018, there is a hierarchy proposed regarding allocation approaches that shall be applied to LCAs and CFPs for lubricants. The hierarchy as outlined in ISO14067:2018 reads as follows:

“1) Wherever possible, allocation should be avoided by:

  a) dividing the unit process to be allocated into two or more sub-processes separately and collecting the input and output data related to these sub-processes; or

  b) expanding the product system to include the additional functions related to the co-products.

2) Where allocation cannot be avoided, the inputs and outputs of the system should be partitioned between its different products or functions in a way that reflects the underlying physical relationships between them.

3) Where physical relationship alone cannot be established or used as the basis for allocation, the inputs should be allocated between the products and the functions in a way that reflects other relationships between them. For example, input and output data might be allocated between co-products in proportion to the economic value of the products.”

This hierarchy, as it shall be applied to LCAs and CFPs for lubricants, is outlined below:

1) Wherever possible, allocation should be avoided.

2) Components that are used in lubricants are often the product of processes that cannot be subdivided; therefore, allocation becomes necessary. In such cases, allocation on physical properties is recommended. For non-energy products like components intended for blending in the lubricant, the physical allocation

should be performed on mass basis. An example of this type of allocation is the production of base oils from a refinery.

3) Should allocation on physical properties not be possible, another relationship should be established between the product and co-products from the process. The economic value of the products is an example of such a relationship.

It should be acknowledged, as the components going into lubricants are often products of larger refinery or chemical production processes, that such scenarios can lead to a mixture of allocation approaches (e.g. allocation on energy content basis when the primary products of upstream processes are energy products and allocation on mass basis when primary products are non-energy products). In such cases, the allocation approach selected shall be clearly documented to make this apparent, and mixing allocation approaches should be avoided wherever possible.

For more details on allocation at end-of-life for used/waste oil, see 5.6.1. Where applicable, in line with the cut-off criteria defined in 4.5, waste generated during raw material production processes should also be accounted for. A future version of this document intends to provide further guidance on this topic.

The topic of allocation is complex, with multiple possible approaches outlined in the above hierarchy. However, when setting out with a new assessment and allocation cannot be avoided, the allocation approach must be validated and transparently documented if deviating from the outline hierarchy. Some specific examples of allocations applied in LCAs and CFPs for lubricants can be found in 4.4.1 through 4.4.3.

4.4.1 Allocation of Utilities

Many manufacturing plants do not have individual meters (sub-metering) at the production units. If installation of sub-metering is not possible, allocation is required to assign utilities, such as electricity consumption and steam consumption, to specific production units, batches, and products.

This technical report proposes allocation of utilities for lubricant products as follows:

- Where limited difference is estimated in the utility consumption per output of product (e.g. per tonne product) for the different production units and products, allocation should be based on mass. For example, this may be a case where the only activities of the site are those of formulating finished lubricant.

- Where the utility consumption per output of product is estimated to show a difference greater than 20 % for the different production units and products, allocation should be based on expert judgment. For example, this may be a case where the lubricant manufacturing site produces both components and blends, or an additive manufacturing site produces different components that have significantly varying energy requirements.

4.4.2 Allocation of Onsite Combined Heat and Power

For onsite combined heat and power (CHP), the allocation of the environmental impacts of the unit to electricity and heat should be based on the efficiency method as outlined in the GHG Protocol document *Allocation of GHG Emissions from Combined Heat and Power (CHP) Plant* [29].

Section 8.5 of PAS 2050:2011 also provides guidance on potential allocation approaches for CHPs, as does EN 15316-4-5:2017.

4.4.3 Allocation of Multi-output Processes for Additives

In addition to the main product being produced, some additive production processes also generate co-products. The product and co-products may vary considerably in terms of their composition, quality, and economic value. To allocate the environmental burdens between the product and co-products, this technical report proposes to follow the guidance provided in the Together for Sustainability (TfS) *Product Carbon Footprint Guideline* document [15]. The TfS methodology was developed for the chemicals industry and aligns well with the methodology described in this technical report. When introducing cradle-to-(additive supplier)-gate figures, which have been derived in accordance with the TfS methodology, into an assessment being performed in accordance with this technical report, attention should be paid, that the allocation approach used in such figures is in alignment with the hierarchy outlined in 4.4.

4.5 Materiality Thresholds and Cut-off Criteria

General considerations regarding cut-off criteria from Section 6.3.4.3 of ISO 14067:2018 and Section 4.2.3.3.3 of ISO 14044:2006 should be consulted by the practitioner when defining the materiality threshold and cut-off criteria for the specific study under consideration. Such thresholds should be tested for appropriateness to the goal and scope of the evaluation using expert judgment. A suggested starting point for setting materiality thresholds on a mass and energy basis could include:

— no more than 2 % contribution to individual components (e.g. by life cycle stage) to the overall environmental impact(s);

— no more than 5 % contribution cumulatively across multiple components to the overall environmental impact(s).

As per section 4.2.3.3.3 of ISO 14044:2006, “environmental significance” could be considered to define additional cut-off criteria, if deemed appropriate.

Application of cut-off criteria can be particularly challenging when faced with missing data, as it can be difficult to judge if the missing contribution is distorting the results of the lubricant under investigation. The topic of missing data is discussed further in 4.7.

One of the general principles of LCA, as defined in Section 4.1 of ISO 14040:2006, is that an iterative approach should be applied. This means that the view on certain inputs falling above or below the defined cut-off criteria could change over time as better information becomes available. Any exclusions made should be transparently documented.

4.6 Data Collection and Hierarchy of Data Sources

In line with industry standards like Section 6.3.5 of ISO 14067:2018, a hierarchy approach should be applied on the selection of data sources to be used to calculate the LCA or CFP for lubricants. Overall, the preference for this technical report is to use primary data, pertaining to activity data, GHG emissions data, and emission factor data, where it is obtainable with reasonable effort. The focus should be on using primary data at least for the value chain segments in which the preparer participates (Scope 1 and Scope 2 emissions), and collection of primary data for upstream processes should be requested.

Although expert judgment is required to assess the inclusion of any individual data sets into the calculation for the LCA or CFP for lubricants, a hierarchy as follows could be applied to guide such inclusion:

1) primary data that are site-specific;

2) primary data from a different but representative product system (e.g. through average across different sites as per Note 2 in Section 6.3.5 of ISO 14067:2018);

3) secondary data for the process under investigation;

4) secondary data from proxy processes or estimates.

Specific aspects on the collection of primary data, broken down by stages of the lubricant life cycle, are captured in Section 5.

Where no primary data are available, secondary data should be used from the following sources:

— data for representative process from recognized LCA databases/software;

- data for representative process from published scientific literature;

- data for representative process from published industry sources.

Where no secondary data for a representative process can be identified, proxy values should be used from the data sources identified above. Such proxy values can be derived from the following:

- using similar production processes;

- tracing the upstream supply chain to raw materials to estimate contributions from required production steps.

On progression down the hierarchy as outlined above, the uncertainty in the estimate will likely increase. Therefore, a conservative approach, consistent with general GHG accounting principles [28] should be applied for selecting data from a scenario in which a range of values is available from different sources. Great care should be applied on the data selection to ensure that the LCA or CFP for the lubricant is not underestimated; conservativeness in the selection of values from a range (e.g. selection of top of the range estimate) can lead to a higher CFP value overall. An iterative approach will drive the selection of data sources toward the use of primary data, improving data quality, reducing uncertainty, and removing the need for conservativeness in the estimates of secondary data over time.

Frequently, for calculations of LCAs and CFPs for lubricants, data will be needed for components from upstream in the supply chain (e.g. raw materials being used in a chemical process). In such cases, to ensure consistency, data should be developed in accordance with the guidance provided in this technical report (e.g. use of applicable standards, allocation approaches, and external independent assurance). If the data cannot be supplied in accordance with this guidance, great care should be taken in drawing conclusions from the study and limitations should be clearly documented.

4.7 Data Quality Assessment and Treatment of Missing Data

Performing an internal quality control on the data used for the assessment, based on the professional judgment of the preparer, is highly recommended. Qualitative data quality scores, although subjective at times, could be used to assess and, if consistently applied, improve data quality over time.

Data quality should assess the following data quality indicators, defined in line with the GHG Protocol, (2011) *Product Life Cycle Accounting and Reporting Standard* [24]:

- Technological representativeness: the degree to which the data reflect the actual technology or technologies used in the process.

- Geographical representativeness: the degree to which the data reflect the actual geographic location of the processes within the inventory boundary (e.g. country or site).

- Temporal representativeness: the degree to which the data reflect the actual time (e.g. year) or age of the process.

- Completeness: the degree to which the data are statistically representative of the process sites.

- Reliability: the degree to which the sources, data collection methods, and verification procedures used to obtain the data are dependable.

Owing to the comparatively new application of LCA to lubricant products, there may be examples where data are not available within the life cycle stage under investigation. Lubricants can often be comprised of a complex mixture of varied chemistries, and the challenge of missing data can be encountered for components comprising the lubricant. If such a gap in the data is encountered, it is recommended to use the hierarchy approach listed in 4.6 to attempt to close the gap. The final stage in the outlined hierarchy would be to select proxy values (e.g. from applicable LCA databases), guided by the professional judgment of the practitioner, to bridge the gap in the missing data. For all treatment of missing data, the conservativeness in approach should be applied as outlined in 4.6.

As per the guidance provided in 4.5 and others, and in accordance with the professional judgment of the practitioner, any exclusions that are made should be transparently documented.

4.8 Biogenic Carbon in Products

Biogenic carbon generated from the consumption of CO_2 during photosynthesis should be considered to be temporarily sequestered in intermediate components intended for blending into the finished lubricant products, and ultimately in the finished lubricant itself. In line with Section 6.4.9.3 of ISO 14067:2018 and Section 3.3 of the GHG Protocol *Product Life Cycle Accounting and Reporting* standard, GHG emissions and removals from biogenic and fossil sources should be reported separately to allow for tracing of biogenic content to the end-of-life stage. This is particularly important for interfaces in the lubricant supply chain, where data are passed from intermediate component suppliers to downstream actors. In addition, in a cradle-to-gate analysis, the temporarily sequestered CO_2 in the form of biogenic carbon can be subtracted from the total kg CO_2e/kg product and documented separately as a net result. In a cradle-to-grave analysis, the biogenic credit can be used to balance any biogenic CO_2 emissions from the re-release of sequestered carbon. As a result, there is no net contribution of the biogenic CO_2 emissions to the CFP.

Biogenic carbon in intermediate components or finished lubricants can be assessed by a combination of ASTM D-6866 and Total Organic Carbon analysis, or by the application of mass balance. A description of the mass balance approach is contained in Section 5.4.2 of ISO 22095:2020 [7]. ASTM D-6866 measures the percentage of carbon present in a sample which is renewable. ASTM D-6866 is a requirement for USDA BioPreferred and other renewable carbon certifications [17]. Total carbon percent of the intermediate component or finished lubricants can be measured to determine kg CO_2e/kg product (product can be either intermediate component or finished lubricant) benefit from the biogenic carbon. For this, a total organic carbon analysis (such as ASTM D5291, DIN13137, or equivalent) should be performed to determine the wt% carbon present in the product.

The data from ASTM D-6866 and Total Organic Carbon analysis can be used to calculate the quantity of temporarily sequestered kg CO_2e/kg as biogenic carbon in the intermediate component or finished lubricant. The following formulas calculate the contributions from biogenic and fossil carbon, respectively.

Attributed to biogenic carbon (biogenic carbon for cradle-to-gate and end-of-life combustion emissions):

$$kg\,CO_2e/kg\,product = (\%total\ carbon \times \%biogenic\ carbon) \times \left(mw_{CO_2}/mw_C\right)$$

Attributed to fossil carbon (fossil carbon for cradle-to-gate and end-of-life combustion emissions):

$$kg\,CO_2e/kg\,product = (\%total\ carbon \times (1-\%biogenic\ carbon)) \times \left(mw_{CO_2}/mw_C\right)$$

where

$\%total\ carbon$	fraction of mass of carbon relative to total mass (e.g. 0.8 for 80 % carbon content);
$\%biogenic\ carbon$	fraction of total embedded carbon that is of biogenic origin;
mw_{CO_2}	molecular weight of carbon dioxide (CO_2);
mw_C	molecular weight of carbon (C).

Confirmation of biogenic content in the final lubricant using primary data is preferred, while tracing of biogenic content, which is established through experimental data in a component used in a blend, is permissible if no major losses of the biocomponent during blending is assured.[6] For primarily fossil-carbon-based lubricants

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[6] Care needs to be used not to apply experimental methods to lubricants with components that have had biogenic content established using a mass balance chain-of-custody approach (ISO 22095:2020), as measured content might not reflect

and lubricants comprised of a mixture of fossil and biogenic carbon, see 5.5 for further details on end-of-life combustion emission factors. For production of components where the biogenic carbon is only a fraction of the total carbon, a mass balance approach can be taken. The CFP of the biogenic carbon fraction should be calculated in accordance with ISO 14067 or equivalent and applied into production mass balance carbon accounting. Independent certification of this mass balance approach, if applied, should be obtained. Secondary data on bioliquid feedstocks can be found in REDII Annex V and Annex VI [25].

In line with Section 6.4.9.2 of ISO 14067:2018, for biomass-derived components, emissions produced in the production of the biomass should be included in the evaluation, including but not limited to cultivation, production, and harvesting of biomass. For feedstock derived from such biomass, emissions of interest furthermore consist of fuel used, the extraction or cultivation of raw materials, annualized emissions from land-use change, processing to target feedstock, and emissions used in transportation.

To account for land use change impacts within the last decades [7] , the physical source of the biogenic carbon should be accounted for in gate-to-grave and cradle-to-gate LCIA and CFP studies. In accordance with Section 6.4.9.5 of ISO 14067:2018, direct land use change (dLUC) should be accounted for using site-specific studies. When a site-specific study is not available, use of internationally recognized methods, such as IPCC Guidelines for National Greenhouse Gas Inventories and Section 5.6 of PAS 2050:2011, is appropriate [26]. dLUC accounting should be included and documented separately in the CFP.

The international community does not currently have agreement on how to fully account for indirect land use change (iLUC) impacts on LCIA and CFP studies. Once international agreement has been reached, inclusion of iLUC should be considered in CFP studies.

4.9 Sensitivity Analysis

In line with Section 4.3.3.4 of ISO 14044:2006, it is recommended to perform a sensitivity analysis to understand the main contributors from the input parameters to the overall study. Keeping the iterative approach for LCA in mind (e.g. Section 4.3 of ISO 14040:2006), such analysis can help to identify areas for further improvement and help to test the assumptions that underpin the overall evaluation. This directs the practitioner toward improvement of parameters, which are likely to have the biggest impact on the overall outcome of the study.

Below are some examples of sensitivity analyses that could be considered:

- Variations in EFs for feedstocks: For example, if secondary data sources are used, exploration of different data sources should be considered to gauge the impact on the overall outcome of the assessment.

- Explore regional variation: For example, probing the influence of raw material sourcing from different regions and associated variation in EFs on the overall outcome of the assessment.

4.10 External, Independent Assurance

Verification of compliance of the undertaken calculation with the applicable standards listed in 4.1 by an independent verification body is recommended.

This can be in the form of a critical review of the model in accordance with ISO 14071:2014 [3], or other external verification of the methodology and calculators against the standard selected. If a comparative assertion is being sought (e.g. direct comparison of two products in the marketplace), with intention for disclosure to the public, such a critical review or external verification is mandatory according to Section 4.2.3.7 of ISO 14044:2006.

Verification bodies that are used should be accredited to carry out such exercises. An example would be that the external verifier maintains a management system that meets accreditation requirements for ISO 14065:2013 [5].

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assigned content.

[7] As per Section 6.4.9.5 of ISO 14067: The IPCC tier 1 period of 20 years is frequently used.

5 Considerations by Life Cycle Stage

This section provides more-detailed aspects to consider when applying LCA methodology to CFP calculations. It is structured according to the stages of the lubricant life cycle as defined in Figure 1 and is intended to provide practical advice on the application of the methodology (e.g. types of parameters to include in the assessment for this life cycle stage). Publicly available data sources that could aid in the application of the guidance provided (organized by life cycle stage) can be found in Annex A.

5.1 Raw Materials

Raw materials make up an important contribution to the LCA and CFP of the product and have been subdivided into two main groups: base oils and re-refined base oils (API Groups I–V), and additives. Lubricants are typically blended from these components (or can be made up of a single component); for a LCA and CFP for a finished lubricant, the product-specific formulation should be used to determine a mass fraction weighting of the contribution by the individual components making up the lubricant.

5.1.1 Base Oils

Guidance on what data to collect to determine the contribution to the LCA and CFP by the base oil has been grouped by base stock: Group I-III and Group IV &V respectively [21].

5.1.1.1 Base Oils and Re-refined Base Oils (API Groups I–III)

To determine the contribution to the finished lubricant CFP from the base oil (BO; API groups I–III) on a cradle-to-refinery-gate basis, primary data from a representative asset on mass flow and energy consumption and type should ideally be used for the basis of the assessment.

Although not an exhaustive list, the following items would be important to consider when gathering data to determine the component contribution from the base oil (BO) or re-refined BO:

1) For base oil—crude oil intake data: The crude oil slate can be used to determine the fraction of crude from different regions/countries, which could be paired with applicable GHG emission factors (EF). The EF by crude types should include at least production and extraction, surface processing, and transport to the refinery inlet. Primary data are preferred to derive applicable EFs, but in absence of primary data, secondary data on country level for such EF have been published by Masnadi et al. [12], for example. Comparable secondary data sources with similar levels of granularity or field-level emission factors could also be used.

2) For re-refined base oil—used oil intake data: For re-refined base oil, the used oil intake data includes the acquisition and processing of used oil into the system, transportation of used oil to terminals, and re-refinery via truck, rail, and barge, as well as the acquisition of chemical, energy, and fuel inputs to the re-refinery's pre-processing that may be performed at the terminal and/or re-refinery level. Per guidance in 5.6.1, the cut-off approach is applied, and used lubricant enters the re-refinement process without upstream emissions (treatment as waste material). For any feedstock not purely based on used and recycled oil; e.g. co-feeding with virgin vacuum gas oil (VGO), data sources listed in Item 1) above need to be consulted to account for crude oil intake and associated upstream emissions.

3) For feedstock with biogenic content: For BOs that contain biogenic carbon, the biogenic carbon content (see 4.8) and the carbon footprint associated with the production and transport must be considered. See 4.8 for details on situations where sustainable material is co-fed to a refinery process, and the share of such materials in the resulting BO needs to be accounted for, either directly or through means of mass-balance [7].

4) Mass flow through the sub-units (e.g. atmospheric distillation, vacuum distillation, solvent extraction, hydrotreater) of the refinery. In alignment with the allocation approach described in 4.4, such mass flow data can be used to determine the mass fractions at each sub-unit, leading to the product of interest. The number of sub-units considered will vary with the refinery lineup.

5) Energy consumption data, broken down by refinery sub-unit: This consumption data should include thermal energy sources (e.g. natural gas, fuel oil or other thermal energy sources), electricity, and steam. Also, any other energy consumption streams in line with the cut-off criteria defined in 4.5 should be considered. For steam production, data on the primary energy mix, efficiency, and transfer losses should also be gathered to determine the associated emissions.

All data should be collected over a representative time period e.g., over a period of one year. If certain parameters are known to significantly vary year-to-year (e.g. significant variation of the crude diet occurs), a longer time period may be warranted to determine a representative average crude intake to the refinery.

To ensure regional representation, based on the professional judgment of the practitioner, EFs representing the geography of the asset under investigation should be used during the assessment of the contribution to the CFP by the BO. Examples could include the use of region-specific grid factors to assess emission attributable to electricity consumption at the site. In line with the life cycle approach of this assessment, EF should also be selected with a life cycle scope in mind (e.g. including upstream contributions).

In line with the data collection approach as outlined in 4.6, data might not be available to this level of granularity for every BO stream at this point in time, in which case primary data from a representative asset should be used to determine carbon intensity ideally differentiated by API base stock categories (e.g. Group I, Group II) [21]. In general, GHG intensity will increase with the degree of necessary processing to produce a certain type of base stock. In absence of site-specific data, this data should be adjusted for resulting uncertainty to be in line with the criteria of “conservativeness” as outlined in 4.6.

The above information can be used to determine the cradle-to-refinery-gate contribution to the CFP for the BO. To estimate emissions associated with the transport of the BO from the refinery to the blender location, refer to 5.1.3.

5.1.1.2 Base Oils (API Groups IV and V)

Group IV and V base oils are those created by combining well-defined raw materials into controlled chemical structures having predictable and tailored properties. Several examples are provided below, but are not limited to:

- polymerization of oligomers (e.g. α olefins, butenes, glycols),
- esters (e.g. linear, branched, and aromatic);
- other synthetic fluids (e.g. silicones, phosphate esters, alkylated aromatics, halogenated fluids).

Group IV and V LCAs on a cradle-to-gate basis should include all relevant life cycle stages. These stages include raw materials used, waste generated, energy flows, and resources introduced or removed via the synthesis processes. Often with many commercial product processes, other activities may need to be considered within boundaries. These activities may include on-site heating or storage, packaging, and filling operations, as they are in the scope of distributing a product to customers.

Synthetic base oil cradle-to-gate life cycle elements may include a collection of some or all of the following data:

- environmental burden inventory for the raw material feedstock(s); this accounting can include credits from raw materials having biogenic source origins (see 4.8) for tracing to the end-of-life stage (5.6.1);
- inbound transport of the raw materials to the manufacturing facility (see 5.1.3);
- mass flow through base oil chemical synthesis plant, to aid with environmental burden allocation to products, by-products in accordance with 4.4 [analogous to Item 4) in 5.1.1.1];
- energy for upstream production and consumption (fuels/electricity/steam) required for the base oil chemical synthesis [analogous to Item 5) in 5.1.1.1];

— upstream burdens associated with resources and their wastes from product synthesis steps (e.g. catalysts, solvents, or neutralizing agents);

— emissions from activities related to the product and associated within the manufacturing organization, such as off-loading raw materials, storage, filling, or packaging operations (see 5.3 and 5.6)

— treatment of end-of-life wastes (e.g. synthesis by-products and/or raw material packaging [see 5.6.2]).

Guidance specific to data selection (4.6), cut-off criteria (4.5), allocation (4.4), and independent assurances (4.10) for the production of synthetic base oils is suggested to be consistent with the details provided within this report. This also includes standard approaches for assessing the impact of packaging, handling, and transportation (see 5.1.3, 5.3, and 5.4) discussed elsewhere in this document.

5.1.2 Additives

5.1.2.1 Introduction to Additives

For a lubricant to meet the requirements of efficient operation and prolonged engine life, extended drain intervals, or other performance criteria, additives are added to base oils to produce the finished lubricant.

Additives are diverse materials, and modern lubricants will contain a combination of them to meet the performance requirements demanded of the lubricant. The main classes of lubricant additives include detergents, dispersants, antiwear compounds, antioxidants, corrosion inhibitors, antifoam, extreme pressure additives, friction modifiers, metal deactivators, pour point depressants, and viscosity modifiers. Their concentration in the finished lubricant will range from parts per million to percentages.

Individual additive components may be combined into additive packages to ensure synergistic and adversarial effects of the additives in the finished lubricant are balanced. Additive packages and individual additives are then blended with base oils to form the finished lubricant.

5.1.2.2 Additive Manufacturing

Additive components are typically manufactured by chemical synthesis, in batch or continuous processes. The most common chemical reactions include condensation, neutralization, and reactions of olefins. After the component is synthesized, it is often purified by distillation and/or filtration. Additive raw materials can include but are not limited to amines, metal oxides, metal salts, phosphorus compounds, sulfur compounds, silicones, olefins, alcohols, and long-chain carboxylic acids. Generally, the carbon content that imparts oil solubility originates from crude oil, but some raw materials may originate from biogenic sources (see 4.8 regarding biogenic carbon).

Additive packages are generally made by simple blending of additive components.

The additive component or package may be diluted with base oil, esters, or other hydrocarbon fluids for ease of handling (e.g. reduce viscosity).

Additives are transported to the finished oil formulator via pipeline or in bulk, totes, intermediate bulk containers (IBCs), drums, or bags by road, rail, and sea.

5.1.2.3 Materiality of Additives

The potential materiality of the additive's CFP on the overall lubricant should be considered as a first step. Those additives that are added to a lubricant in the part per million range are unlikely to have a material impact on the lubricant overall CFP. See 4.5 for the discussion on materiality thresholds and cut-off criteria.

The optimal case is to have a specific cradle-to-gate CFP for each additive or additive package used in a lubricant, obtained through suppliers or from data sources per hierarchy of the data sources provided in 4.6. The cradle-to-gate CFP must include all relevant life cycle stages, such as the extraction of raw materials (e.g. extraction, purification, and processing of metal ores to form the metal compounds that are used to make a metal-based additive), all intermediate stages of processing, additive production and transportation between upstream sites, and inbound transportation to the additive manufacturing site. The preference is for independently reviewed/verified CFPs, where available (see 4.10).

The standard approaches for assessing the impact of packaging, handling, and transportation discussed in 5.1.3 should be followed.

5.1.3 Inbound Transport and Packaging for Raw Materials

To estimate the emissions associated with the transport of raw materials to the production location (5.2), the following data should be collected:

1) mass of component transported;

2) distance over which the goods are transported;

3) mode of transport used (like road, rail, ship) including fuel type, if available.

Unless emissions data can be supplied by the logistics company (e.g. based on fuel consumption information), EFs for different modes of transport on a kg CO_2e/t.km basis can be sourced from a variety of publicly available sources, e.g. the Global Logistics Emissions Council (GLEC) framework [14].

For a more detailed discussion on transport/logistics emissions, see 5.4.

Inbound packaging materials should be considered for raw materials; for details on potential emission factors by pack type, refer to 5.3.

More detailed considerations for the inbound transport and packaging of base oils and additives:

NOTE 1 The formulation for most commercial lubricant formulations will consist principally of BOs and base stocks. Considering the prevalence of BOs, most LBPs will receive these components primarily in bulk form, conveyed by either tanker truck, railcar, barge, and/or ship. However, some specialized and/or lower-consumption base stocks/base oils are received in smaller quantities; in such cases, drums and/or intermediate bulk containers (IBCs) are frequently used.

NOTE 2 In comparison to BOs, additives may typically be received in smaller containers (e.g. pails); solids are frequently received packaged in bags (polymeric and paper bags are both common), with the bags in turn palletized. Similar to other packaging materials, the choice of pallet material (wood vs. plastic) may have sustainability implications. The supplier should be requested to provide a life cycle EF that considers the service life and recyclability of the pallet.

5.2 Production

Considerations of contribution to the CFP from the blending operations of the lubricant at the lubricant blending plant (LBP) are discussed below.

To determine the contribution, the following type of data should be collected from the asset inventory:

- consumption of thermal energy (e.g. natural gas, or other energy carrier);
- consumption of imported electricity;
- consumption of imported steam;
- fuels consumed for onsite transports (unless included above);
- waste lubricant from production and disposition of such waste (for oil disposal fates, see 5.6.1);
- lubricant production volume;

— packaging and filling data (if applicable).

All data should be collected over a representative time period (e.g. over a period of one year).

More-detailed considerations of aspects that can contribute to consumption of energy, and therefore, production of emissions at the LBP, can be accessed in Annex D.

5.3 Packaging

To estimate the contribution from packaging to the overall product CFP, the packaging present at different stages of the life cycle should also be considered on a life cycle basis. The contribution on a cradle-to-gate basis is discussed in this section, while end-of-life treatment of packaging is covered in 5.6.2; both of these sections cover the life cycle of the packaging material.

For the estimation of the cradle-to-gate contribution from primary packaging (packaging in direct contact with the lubricant), the following data should be gathered:

— raw material type (e.g. steel, plastic like HDPE);

— raw material weight;

— nature of raw material (virgin or recycled);

— packaging production process energy consumption (e.g. plastic blow molding);

— thermal energy source used for packaging production;

— reuse of packaging materials (rewashing of IBCs).

The data above can be used to select applicable emission factors for raw materials (e.g. kg CO_2e/kg of recycled HDPE; see 4.6) in combination with the contribution from production (e.g. kg CO_2e/kWh of electricity/heat required) to estimate the contribution from fabrication. Inbound transport to the production facility and associated packaging material (packaging of packaging materials, e.g. palleting, if applicable) should also be included. If a pre-calculated emission factor for a specific pack type from a secondary data source is to be used instead, the alignment of the assumptions for that emission factor should be tested against the collected data (e.g. are the raw material weights comparable).

NOTE 1 Given that diverse packaging options are available and also may be different for the various life cycle stages, it is preferred to express emissions associated with packaging in the assessment documentation separately.

NOTE 2 The contribution from labeling should be evaluated in light of the cut-off criteria (4.5). The label supplier could be approached for an EF accounting for offsite production of labels followed by transport of labels to the packaging site (e.g. LBP). If onsite spray-on application of labels is performed, associated energy consumption could already be included in the inventory gathered for the “production” stage (5.2).

NOTE 3 Specialty case of onsite packaging manufacturing: Rather than receiving smaller packages (e.g. 1-quart or 1-liter bottles) from a package manufacturer, some LBPs implement onsite blow-molding operations to create the bottles from polymeric resin. This will allow for direct collection of packaging production data, but care should be taken that associated production energy consumption is also not included in the inventory gathered for the “production” stage (5.2).

5.4 Logistics

This section covers the contribution to the LCA (and in terms of emission to the CFP) for distribution of the finished lubricant from the lubricant production gate to the customer gate. Although important to consider as an area for improvement, the contribution from logistics to the overall CFP tends to be smaller, with exceptions for special circumstances of intercontinental import or air-freight transport.

To estimate the emission associated with the transport portion of the life cycle of finished lubricants to the customer, the following data should be collected:

1) mass of finished lubricant transported;

2) distance over which the goods are transported (from/to location data);

3) mode of transport used (like road, rail, ship), including fuel type, if available.

EFs for different modes of transport on a kg CO_2e/t.km basis can be sourced from a variety of publicly available sources (Annex A). A recent example of a suitable data source could be the Global Logistics Emissions Council (GLEC) framework, which references EPA SmartWay as a data source for U.S. heavy goods road transport [14].

For different modes of transport (like road, rail, ship), there is a range of values available by transport types (e.g. different types of trucks for road transport), so guidance by the hauler or, if applicable, the logistics department should be sought to select the most appropriate EF based on logistics fleet composition. Most of the transport for finished lubricant products will be via road transport, where EFs can be further differentiated by load factor and degree of empty running. Truck transport could include customer pickup, in-house delivery fleets, and third-party hauling services.

More complex distribution patterns, which also vary over time, might require an approach of using averaged data over a representative time period (e.g. minimum of one year). This approach is more suitable for a product sold to a variety of customers, where tracing of individual transactions becomes prohibitively complex, with additional granularity only making a minor difference to the overall CFP.

Alternatively, if fuel consumption data are available from the hauler or if logistics is under operational control (and hence such primary data on fuel consumption is available for collection), this should be used for the estimation of the transport-associated emissions, as this is usually a more accurate assessment. The fuel consumption data should be paired with well-to-wheel (WtW) emissions factors for the fuel types from recognized sources [14, 16, 23]. If hauler data are already supplied and converted to CO_2e, the data source for the EFs used for the conversion should be determined and calibrated against data sources quoted above (e.g. if the same EF scope is covered, are values provided within 5 %?). As per the general guidance in 4.6, gaps in the data should be bridged with conservative estimates informed by the best available data.

While transport-related emissions will be the main contribution to this life cycle stage, other activities could contribute additional emissions and could be evaluated if sufficiently granular data are available:

— Warehousing at different stages of the value chain: Conservatively estimated default values show that this is likely to be a small contribution to the logistics section [22].

— If not reflected elsewhere (e.g. transport type EF or asset-specific accounting), energy requirements for on- and off-loading could be considered. Also, if applicable in special circumstances where additional heat is required during transport (e.g. to maintain fluidity), an estimation should be performed to assess a potential contribution to the overall CFP.

— In light of the cut-off criteria (4.5), the impact of product returns (e.g. for repatriating non-conforming, adulterated, or past-expiry product) should be evaluated.

5.5 In Use

The “use” stage is part of the life cycle where a lubricant is put into service, by an end consumer, based on its market design and function. The in use stage begins when the end consumer takes possession of the lubricant. This stage extends through a lubricant’s useful life to the point of final disposition, reuse for a different function, recycling, or energy recovery. Within the in use stage, contributions to GHG emissions from activities and energy consumed during lubricant use are determined. The life cycle scope for the in use stage shall specify the user and lubricating environment, along with the product’s use profile.

Factors that influence GHG emissions within the in use stage include losses through combustion, volatility, or leakage out of the lubricating environment. A lubricant's use profile describes its typical performance under realistic conditions of use and contribution to the impact associated with these losses. The use profile for a lubricant should be determined with relevant data to the extent possible. When profile data are not available, estimations of a lubricant performance under realistic conditions within the lubricating environment are acceptable.

Use profile data:

— shall be documented and verifiable

— shall be based on function, market, and intended use

— can be obtained from regulators, equipment manufacturers, relevant industry groups, academia or lubricant marketers, industry applicable qualified testing facilities

If no method is established for use profile data, estimates or modeling may be used to define use profile features. Estimates should be documented by the organization carrying out the CFP and LCA study.

With the fraction of lubricant lost (Figure 3) defined in the "profile data" (MF_{use} = mass fraction of lubricant lost at "in use" stage), the contribution to the CFP can be calculated. Unless other information is available, it shall be assessed that complete combustion takes place.

The contribution to CFP from the "in use" stage can be expressed with the formula below:

$$Contribution\ to\ CFP\ for\ "in\ use"\ stage\ =\ MF_{use} \times EF_{CC}$$

where

A mass fraction (e.g. MF_{use}) is defined as a ratio of mass over total lubricant mass and is unitless;

MF_{use} mass fraction of lubricant lost in use based on "use profile data";

EF_{CC} complete combustion emission factor (all contained carbon released as CO_2).

The emission factor for complete combustion (EF_{CC}) assumes all the carbon embedded in the product to be released as CO_2. Building on the formula provided in 4.8, when the product is only based on fossil carbon, the emission factor can be estimated as follows:

$$EF_{CC}\colon kg\ CO_2/kg\ product\ =\ (\%total\ carbon)\ \times\ \left(mw_{CO_2}/\ mw_C\right)$$

where

$\%total\ carbon$ fraction of mass of carbon relative to total mass (e.g. 0.8 for 80 % carbon content);

mw_{CO_2} molecular weight of carbon dioxide (CO_2);

mw_C molecular weight of carbon (C).

In alignment with 4.8, for a product that is based on both biogenic carbon and fossil carbon, the emission factor to account for the fossil portion of the emissions can be estimated as follows (example of application of this formula provided in Annex B):

$$EF_{CC}\colon\ kg\ CO_2/kg\ product\ =\ \left(\%total\ carbon \times (1 - \%biogenic\ carbon)\right) \times \left(mw_{CO_2}/mw_C\right)$$

where

$\%total\ carbon$ fraction of mass of carbon relative to total mass (e.g. 0.8 for 80 % carbon content);

$\%biogenic\ carbon$ fraction of total embedded carbon that is of biogenic origin;

mw_{CO_2} molecular weight of carbon dioxide (CO_2);

mw_C molecular weight of carbon (C).

The percentage of total carbon content ($\%total\ carbon$) can be estimated using knowledge of the composition of the underlying lubricant product or can be experimentally determined through methods such as ASTM D5291, DIN13137,or equivalent.

NOTE In the absence of such direct figures, recognized secondary data sources have published complete combustion emission factors for used oil, e.g. on the EPA GHG emission factors hub [23] and by the U.K. Department for Business, Energy and Industrial Strategy (formerly DEFRA) [16]. Further details on such secondary data sources can be found in Annex A.

Additional sources of emissions within the in use stage that may apply include energy associated with lubricant storage, distribution, and wastes generated from maintenance activities such as lubricant flushing and or changeover (see 5.4 and 5.6.1 in this context). When included in the life cycle study, these should be transparently documented with their associated activities.

5.6 End-of-Life

5.6.1 End-of-Life—Used Oil

The end-of-life stage begins at the end of the lubricant's service life, i.e. when the lubricant's useful life has been expended and it becomes used oil. Therefore, this section focuses specifically on the material that remains following the "in use" stage (5.5).

NOTE For example, where 35 % of the lubricant has been lost at the "in use" stage due to combustion and leakages, the remaining 65 % of the lubricant still needs to be accounted for at the "end-of-life" stage (Figure 3).

The used oil can go into two types of treatment channels:

1) a fraction that arrives at "formal" treatment channels, so the fate of the used oil can be traced;

2) a fraction that arrives at "informal" treatment channels, where the fate of the used lubricant is unknown due to untraceable disposal practices (e.g. combustion of used oil in space heaters at workshops).

The fate of the used oil shall be accounted for, no matter what the treatment channel is. Due to the unknown nature of "informal" treatment channels, these shall be conservatively estimated in a way that all the embedded carbon is assumed to be released as CO_2 (via use of the "complete combustion emission factor" EF_{CC} defined in 5.5). The volume of used oil entering "informal" treatment channels shall account for the difference in volume of used oil available after the "in use" stage and used oil arriving in traceable "formal" treatment channels.

Used oil arriving at "formal" treatment channels typically undergoes one of four fates:

1) recycling of used oil (e.g. re-refining);

2) combustion of used oil with heat recovery;

3) combustion of used oil for disposal (no heat recovery);

4) landfill of used oil.

The contribution to the end-of-life stage from each of the four fates to the CFP is given by an applicable emission factor.

The overall contribution to the CFP from the end-of-life stage can be expressed with the formula below:

$$\textit{Contribution to CFP for end-of-life stage} \; =$$

$$MF_{EoL} \times F_{informal} \times EF_{CC} + MF_{EoL} \times F_{formal} \times$$

$$\left(F_{recycle} \times EF_{recycle} + F_{CHR} \times EF_{CHR} + F_{CD} \times EF_{CD} + F_{landfill} \times EF_{landfill}\right)$$

where

$MF_{EoL} = 1 - MF_{use}$ embedded carbon in the product that remains after the “in use” stage;

$F_{informal} + F_{formal} = 1$ MF_{EoL} is subdivided into informal and formal treatment channels;

$F_{recycle} + F_{CHR} + F_{CD} + F_{landfill} = 1$ applies to lubricant waste undergoing formal waste treatment.

Definition of symbols from previous formula:

A mass fraction (e.g. MF_{use}) is a ratio of mass over total lubricant mass and is unitless.

MF_{use}	mass fraction of lubricant lost in use based on use profile data.
MF_{EoL}	mass fraction of lubricant entering the end-of-life stage.

A fraction (e.g. $F_{informal}$) is the ratio of mass entering a treatment channel over the combined mass that remains to be accounted for (e.g. total mass entering the end-of-life stage). A fraction is unitless.

$F_{informal}$	fraction of used oil entering informal treatment channels.
F_{formal}	fraction of used oil entering formal treatment channels.
$F_{recycle}$	formal fate—fraction of used oil undergoing recycling.
F_{CHR}	formal fate—fraction of used oil undergoing combustion with heat recovery (CHR).
F_{CD}	formal fate—fraction of used oil undergoing combustion for disposal (CD).
$F_{landfill}$	formal fate—fraction of used oil being disposed in a landfill.

Emission factors will carry the unit of kg CO_2/kg.

EF_{CC}	complete combustion emission factor (all embedded carbon released as CO_2).
$EF_{recycle}$	emission factor for recycling of used oil.
EF_{CHR}	emission factor for combustion of used oil with heat recovery.
EF_{CD}	emission factor for combustion of used oil for disposal.
$EF_{landfill}$	emission factor for disposal of used oil in landfill.

An overall formula showing the combined contribution to the CFP from the use (5.5) and end-of-life stages is provided in Annex B alongside examples for applications of this formula.

To estimate the GHG emissions associated with the end-of-life stage according to the formula provided above, the following type of data are required:

— split of used oil undergoing informal or formal end-of-life treatments;

— split into four main used oil formal fates as defined above.

Such data will vary regionally, and the factors selected should reflect this variation. Where available, country level data should be obtained to provide additional granularity over regional/global averages. Annex A provides potential data sources for such factors.

NOTE For example, a recent report from the U.S. Department of Energy (DOE) provides insights for such parameters for the United States [18].

For used oil treatment fates, where downstream parties derive a benefit from the treatment approach (e.g. recycling of used oil) a cut-off approach shall be used. Therefore, the emissions associated with those used oil treatment fates will be outside the system boundary and carried by the beneficiary.

The four main formal fates of used lubricant and associated emission factors are discussed in more detail below:

1) Recycling of used oil:

   The used oil has been declared to be destined for reclamation [8] /re-refinement and recycling. Through application of the cut-off approach, the used oil associated with this fate leaves the system boundary for the life cycle assessment of the lubricant product, and the emissions shall be attributed to the system of the beneficiary from use of the recycled material (in this case, the re-refiner). The point where the material destined for recycling leaves the system boundary is therefore the start point as the "raw material" for the re-refined base oil process (as defined in 5.1.1.1). It should be noted that the used oil carries no upstream emissions burden, which has already been fully accounted for in the "raw materials" stage contribution of the first life cycle of the lubricant product. [9]

   When the cut-off approach is applied, the applicable emission factor for the CFP calculation for the life cycle of the current lubricant is $EF_{recycle}$ = 0 kg CO_2e/kg.

   NOTE Application of the cut-off approach avoids double counting of the embedded carbon emissions when the recycled material reaches the end-of-life stage, again having run through the life cycle as defined in Figure 1 for a second time.

2) Combustion of used oil with heat recovery:

   The used oil has been declared to be destined for combustion, with the associated released energy being used (e.g. providing heat through combustion of the used oil in a cement kiln). Application of the cut-off approach, consistent with the approach for the recycling fate detailed above, means that the used oil leaves the system boundary for the life cycle assessment of the lubricant product, and combustion-related emissions shall be carried by the party benefiting from the use of the released energy.

   Depending on where the boundary is drawn, there may be transport-related emissions that need to be accounted for (e.g. transport to the waste facility). If used oil collection is performed by the downstream beneficiary of the energy use, the applicable emission factor is EF_{CHR} = 0 kg CO_2e/kg. This means that emissions associated with the used lubricants transport and emissions from combustion of the lubricant are outside of the system boundary.

   For consistency with the approach adopted for the recycling of used oil, adoption of the cut-off approach for this waste fate is the recommended route for this technical report. However, potential alternative approaches that are not recommended by this technical report can be found in Annex C.

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[8] Reclamation: The used oil may be filtered, dewatered, and re-used as a lubricant. This definition encompasses applications when the used oil returns as a lubricant with minimal re-processing.

[9] If feedstock is supplemented with virgin VGO, the associated upstream emissions shall be accounted for, based on the mass fraction that the virgin VGO is contributing to the produced base oil.

3) Combustion of used oil for disposal (no heat recovery):

The used oil has been declared to be destined for combustion, but solely for the purpose of disposal of the waste and without use being made of the released energy (disposal by incineration). Therefore, no other party is deriving a benefit from the disposal and the emissions associated with the release of the embedded carbon are within the system boundary and part of the lubricant product life cycle.

There might be transport-related emissions that would need to be accounted for (e.g. transport to the waste facility), which can be evaluated based on the cut-off criteria (4.5). If used lubricants transport emissions are negligible, the associated emission factor would simplify to $EF_{CD} = EF_{CC}$.

4) Landfill of used oil:

The used oil is disposed of in a landfill. Due to the unknown nature of the fate of the lubricant over a 100-year time frame for such disposals, these should be conservatively estimated as all the contained carbon to be released as CO_2. Again, no other party is deriving a benefit from this type of disposal; therefore, emissions associated with the release of the embedded carbon are within the system boundary and part of the lubricant product life cycle.

There might be transport-related emissions that would need to be accounted for (e.g. transport to the waste facility), which can be evaluated based on the cut-off criteria (4.5). If used oil transport emissions are negligible, the associated emission factor would simplify to $EF_{landfill} = EF_{CC}$.

5.6.2 End-of-Life—Packaging Materials

The end-of-life stage for packaging commences when the associated lubricant product has been dispensed and the packaging material becomes a waste material. To ensure that the life cycle emissions for the packaging material are covered, this section needs to account for the emission that take place following the “cradle-to-gate” scope as defined in 5.3. The end-of-life contribution from packaging to the overall CFP is usually limited, due to the relatively low weight of packaging in relation to the packed material.

To calculate the end-of-life contribution from primary packaging (packaging in direct contact with the lubricant), the following data are required:

— weight of packaging (by raw material type);

— data on proportional disposition by country/region and waste material type into four main waste fates: recycling, combustion with heat recovery, combustion without heat recovery, and landfill;

— emission factors by waste material type and waste fate (e.g. polyethylene—incineration without energy recovery).

The approach selected for end-of-life for packaging should be consistent with the approach for used oil. Therefore, if the cut-off approach is used, the emission factors for the waste fates of recycling and combustion with energy recovery should be set to 0 kg CO_2e/kg, as the associated emissions are carried by the downstream beneficiary.

NOTE Due to oil contamination, recycling of lubricant plastic bottles is only possible in a limited number of countries where legislation is in place to address this challenge. This should be considered when the waste fate splits by country/region are determined.

Additional contributions to this stage of the life cycle from transport of the waste to the waste disposal facility should be considered.

6 Applications of Outcome of Lubricant LCA

This section is intended to explore potential application areas of the outcome of LCA and CFP studies of lubricant products. Common applications for the potential benefits of lubricants may include efficiencies obtained through service consisting of lower fuel or electricity use, and less oil used over a given functional unit. As per Section 1, this section is not intended to be an exhaustive treatment of these topics, but to rather provide some examples with high-level guidance.

6.1 Avoided Emissions Through Fuel Economy Benefits

Avoided emissions are estimated based on a comparative study in which a product solution in terms of its greenhouse gas (GHG) emissions impact is compared with an alternative product that provides an equivalent function (reference solution or functionally relevant baseline) [19]. If the product solution leads to overall lower GHG emissions in this comparison, the delta would be referred to as "avoided emissions". Avoided emissions stand separately and in addition to the lubricant life cycle assessment and the defined CFP of the lubricant.

One example of such "avoided emissions" that is applicable to lubricants is emissions that are avoided due to fuel economy benefits offered by a lubricant product with a use profile differentiated by fuel consumed when compared with a functionally relevant baseline.

To estimate such "avoided emissions" at a high level, four figures need to be compared with each other:

- The CFP of the lubricant product against the CFP of the functionally relevant baseline solution: The absolute emissions difference is determined by the volume requirement of the application (both CFPs should be determined in the same manner in line with this technical report).
- Comparison of fuel economy benefit afforded by the lubricant product in comparison to the fuel economy benefit afforded by the functionally relevant baseline solution: The difference in fuel not consumed is translated into avoided CO_2e emissions using recognized tank-to-wheel and well-to-tank emission factors.

NOTE Potential sources for applicable emission factors [16, 23].

Careful consideration is needed to apply appropriate scopes, boundaries, and functional units for the output analysis to drive consistency and allow for relevant comparisons.

If the improvements of the fuel economy savings outweigh the difference in CFPs, there is emission avoidance overall. As these two pairs of figures are derived on quite different basis (sum of absolute life cycle emissions contributions vs. avoided emissions from unburned fuel), they should be shown side by side rather than directly subtracted from each other. In this particular case, the study touches on a different product life cycle (extended boundary output)—fuel that is not combusted due to the fuel economy benefit.

This type of avoided emission study is strongly dependent on the robustness of the underlying fuel economy data. Therefore, industry recognized fuel economy test methods should be used for quantification, where available. The test method used should be clearly documented.

Furthermore, credibility of such a study to determine avoided emissions is dependent on the realism of the point of comparison and the reference/baseline [10] selected. Guidance on how to define a suitable "reference" or "functionally equivalent baseline" can be found in Section 3.2 of a study by the International Council of Chemical Associations (ICCA) and the World Business Council for Sustainable Development (WBCSD) [20]. Some of the contained guidance has been quoted below for reference:

"The solution to compare with shall meet several criteria to ensure a credible avoided emissions claim:

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[10] In certain engine tests, performance is measured against a "reference lubricant," which is often of a higher viscosity grade (e.g. 15W-40) than viscosity grades generally found in the marketplace today, and hence would not be a suitable reference/baseline to determine avoided emissions.

— Ideally one wants to compare the studied solution to what the studied solution really replaces.

— The solution being replaced could be the market average, an average of several solutions of the market, a very specific solution, the dominant solution, or a marginal solution […]"

As part of the associated documentation, the reference/baseline selected and how the comparison to the reference/baseline was performed shall be stated transparently.

NOTE A recent study that was commissioned by the Technical Association of the European Lubricants Industry (ATIEL), highlights the overall avoided emissions enabled through lubricants for the EU vehicle fleet as the market transitions to lower-viscosity lubricants [13]. The magnitude of the avoided emission quantified both backward looking to 2005 and forward looking to 2030, highlights the significant contribution of lubricants to the decarbonization of the road transport sector.

6.2 Avoided Emissions from Extended Oil Drain Interval

Another source of avoided emission applicable to lubricants is emissions avoided through extension of the oil drain interval (ODI).

For this type of avoided emissions estimation, at a high level, the following steps and data will be needed to draw a comparison:

— The CFPs for the lubricant [11] under investigation and for the lubricant being used as the functionally relevant baseline need to be determined (converted via respective densities to kg CO_2e/liter; both CFPs should be determined in line with this technical report).

— Required lubricant volume based on sump size [12], normalized to the extended ODI should be determined (e.g. if the lubricant under investigation doubles the ODI, while providing equivalent fuel economy performance, twice the volume of the baseline lubricant is needed to cover the same ODI in the same application. For a 5 L sump and without top-ups, this would result in the following: 5 L of lubricant under investigation vs 10 L of baseline lubricant.)

— Multiplication of the CFPs with their respective required volume determines the associated GHG emissions over a given ODI interval for both lubricants.

— The delta of these GHG emission figures for the two lubricants being compared yields the associated avoided emissions from the ODI extension.

Overall, this equates to a change of the functional unit from the functional unit described in 4.2; emissions are no longer provided relative to the lubricant mass or volume, but rather to the new extended ODI interval (e.g. emissions in kg CO_2e associated with the lubricant life cycle required to enable vehicle Z to travel 10,000 miles; therefore, kg CO_2e/10,000 miles in vehicle Z). Both lubricants would be compared using this revised functional unit.

This type of estimation is dependent on the robustness of the data quantifying the extension of the ODI duration. The test method used should be clearly documented.

The guidance regarding the selection of a realistic reference/functionally relevant baseline, as outlined in 6.1, remains applicable for this section.

NOTE As practitioners perform estimations for avoided emissions, there are many different factors to consider, such as oil consumption, weather/environment/changes in the fluid that impact fuel economy, and associated emissions. These factors need to be considered on a case-by-case basis to provide realistic benefit estimation for a given application/end user.

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[11] With a use profile differentiated by lower oil volume over a functional unit equal to the lubricant used for comparison.

[12] Any top-up volume needed should be included.

6.3 Supporting “Carbon Neutral” Claims on Products

Section 7.17.3.2 of ISO 14021 defines “carbon neutral” and for a product provides the following definition:

“[…] carbon neutral requires that all the GHG emissions from all stages of the product life cycle, and within the specified product system, have been reduced, removed, or accounted for through a system of offsetting or credits, or by other means [4].”

ISO 14021 also references ISO 14067 for guidance on determination of a carbon footprint of product (CFP). That document is one of the normative references provided in Section 2 of this technical report. Based on this definition, a CFP [13] that is derived on cradle-to-grave basis, in line with the applicable selected standard (e.g. ISO 14067) and aligned with the guidance of this technical report, would need to be determined as an important step toward a “carbon neutral” claim. All associated life cycle emissions determined in this fashion would then need to be shown to be avoided/reduced or offset to reach “carbon neutrality”.

PAS 2060, released by BSI in 2014, gives more detailed guidance on the demonstration of carbon neutrality. This includes guidance on permissible declarations, ongoing documentation in the form of a carbon footprint management plan, and actions to be taken to maintain carbon neutrality on an annual basis. Annex C of PAS 2060 also provides a list of standards and codes that could be used for the quantification of a carbon footprint of a product or service. These include PAS 2050, the precursor to ISO 14067 [14] , and the GHG Protocol *Product Life Cycle Accounting and Reporting Standard*, all of which are listed as normative references in Section 2.

It should be noted that standards covering carbon neutrality are still evolving. ISO is currently preparing ISO 14068, which, similar to PAS 2060, will provide additional guidance and requirements in this space; it is set for release in 2023 [8].

While further requirements around carbon neutrality are being defined, reliable and robust quantification of the CFP will remain a key step.

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[13] In line with ISO 14067:2018, Section 3.1.1.7, carbon offsetting is not allowed in the quantification of a CFP or a partial CFP.

[14] PAS 2060 was released in 2014 and predates the release of ISO 14067 in 2016.

Annex A
(informative)

Publicly Available Data Sources

Table A.1—List of Publicly Available Data Sources

Source	LCA Stage	Description	Link
API	End-of-life	*Life Cycle Assessment of Used Oil Management* (2017)	https://www.api.org/~/media/Files/Certification/Engine-Oil-Diesel/Publications/LCA-of-Used-Oil-Mgmt-ERM-10012017.pdf
ATIEL	Avoided emissions	*Lubricants’ contribution to fuel economy*; Ricardo Energy & Environment	https://atiel.eu/wp-content/uploads/2021/04/DOC-20.pdf
CalRecycle	Loss in use	California used oil LCA; losses during use phase by lubricant type; Kline and Company	https://www2.calrecycle.ca.gov/Publications/Details/1512
CIMAC	General resource	Internal Council on Combustion Engines	https://www.cimac.com/publications/guidelines/index.html
DEFRA (U.K.)	Loss in use/ end-of-life	Emission factor for combustion, 2021	https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2021
DOE	End-of-life	Waste fate material flows; U.S. market; *Used Oil Management and Beneficial Reuse Options to Address Section 1: Energy Savings from Lubricating Oil*	https://www.energy.gov/sites/prod/files/2020/12/f81/Used%20Oil%20Management%20and%20Beneficial%20Reuse%20Options%20to%20Address%20Section%201.%20E....pdf
Ecoinvent	Packaging	Emission factors for raw materials (e.g. plastics, metal)	https://ecoinvent.org/
Ecoinvent, general	End-of-life	General introduction; waste material compositions; municipal waste collection	https://www.doka.ch/13_I_WasteTreatmentGeneral.pdf
EPA	End-of-life	Emission factors for used oil	https://www.epa.gov/climateleadership/ghg-emission-factors-hub
EPA, AP-42	General resource	Fuel oil combustion	https://www3.epa.gov/ttnchie1/ap42/ch01/final/c01s03.pdf
EPA, eGRID2014	General resource	Grid factors	https://www.epa.gov/sites/default/files/2015-10/documents/egrid2012_summarytables_0.pdf
EPA Facts and Figures	End-of-life	Looks at generation, recycling, composting, combustion with energy recovery, landfilling for a variety of materials and products, and other pathways for food	https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/guide-facts-and-figures-report-about#Materials_and_Products

Table A.1—List of Publicly Available Data Sources (Continued)

Source	LCA Stage	Description	Link
EPA GHG Calculator	Conversion reference	This calculator may be useful in communicating a greenhouse gas reduction strategy, reduction targets, or other initiatives aimed at reducing greenhouse gas emissions	https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator
EPA, NEPIS	General resource	*Life Cycle Inventory (LCI) Data Treatment Chemicals, Construction Materials, Transportation, On-site Equipment, and Other Processes for Use in Spreadsheets for Environmental Footprint Analysis (SEFA)*	https://nepis.epa.gov/Exe/ZyNET.exe/P100SNDQ.
EPA, Scope 3	General resource	Scope 3 emissions are the result of activities from assets not owned or controlled by the reporting organization, but that the organization indirectly impacts in its value chain.	https://www.epa.gov/climateleadership/scope-3-inventory-guidance
EPA, Vermont Used Oil Study	End-of-life	*Vermont Used Oil Analysis and Waste Oil Furnace Emissions Study*	https://www3.epa.gov/ttn/catc/dir1/w_oilacr.pdf
ERASM	General resource	Environment and health; risk assessment and management	https://www.erasm.org/
Eurostat	End-of-life	Waste fate material flows; E.U.; EuroStat Data Browser; waste category: used oil; data can be split by waste management operation	https://ec.europa.eu/eurostat/databrowser/view/ENV_WASTRT__custom_429516/default/table?lang=en
GaBi (now called “LCA for Experts”)	General	Databases; cross-sector calculation tool	https://ghgprotocol.org/gabi-databases
GHG Protocol—CHP	Allocation	*Allocation of GHG Emissions from a Combined Heat and Power (CHP) Plant*	https://ghgprotocol.org/sites/default/files/CHP_guidance_v1.0.pdf
GLEC	Logistics	Emission factors by transport type	https://www.smartfreightcentre.org/en/downloads/

Table A.1—List of Publicly Available Data Sources (Continued)

Source	LCA Stage	Description	Link
GREET	General resource	*Greenhouse gases, Regulated Emissions, and Energy use in Technologies Model*; Argonne National Laboratory	https://greet.es.anl.gov/
PEF	General resource	Multi-criteria measure of the environmental performance of a good or service throughout its life cycle	https://ec.europa.eu/environment/eussd/pdf/footprint/PEF%20methodology%20final%20draft.pdf
Springer Link	General resource	*LCA of petroleum-based lubricants: state of art and inclusion of additives*	https://link.springer.com/article/10.1007/s11367-012-0437-4?utm_medium=affiliate&utm_source=commission_
Springer Link	Uncertainty	*How to treat uncertainties in life cycle assessment studies?*	https://link.springer.com/article/10.1007/s11367-018-1477-1?utm_medium=affiliate&utm_source=commission_
Wiley	Biolubricant	*A sustainability Assessment of a Biolubricant*	https://onlinelibrary.wiley.com/doi/pdfdirect/10.1162/108819803323059460

Annex B
(informative)

Applications of “In Use” and “End-of-Life” Formula

In alignment with Figure 3, to determine the contribution to the CFP from the “in use” (5.5) and “end-of-life” stage (5.6.1), an overall formula for the release of embedded carbon in the lubricant could look as follows.

Contribution to CFP for both “in use” and “end-of-life” stages =

$$MF_{use} \times EF_{CC} +$$

$$MF_{EoL} \times F_{informal} \times EF_{CC} +$$

$$MF_{EoL} \times F_{formal} \times \left(F_{recycle} \times EF_{recycle} + F_{CHR} \times EF_{CHR} + F_{CD} \times EF_{CD} + F_{landfill} \times EF_{landfill}\right)$$

where

$MF_{use} + MF_{EoL} = 1$	total embedded carbon in the product is accounted for;
$F_{informal} + F_{formal} = 1$	MF_{EoL} is subdivided into informal and formal channels; and
$F_{recycle} + F_{CHR} + F_{CD} + F_{landfill} = 1$	applies to lubricant waste undergoing formal waste treatment.

Definition of symbols from previous formula:

A mass fraction (e.g. MF_{use}) is defined as a ratio of mass over total lubricant mass and is unitless.

MF_{use}	mass fraction of lubricant lost in use based on “use profile data.”
MF_{EoL}	mass fraction of lubricant entering the end-of-life stage.

A fraction (e.g. $F_{informal}$) is the ratio of mass entering a treatment channel over the combined mass that remains to be accounted for (e.g. total mass entering end-of-life stage). A fraction is unitless.

$F_{informal}$	fraction of used oil entering informal treatment channels.
F_{formal}	fraction of used oil entering formal treatment channels.
$F_{recycle}$	formal fate—fraction of used oil undergoing recycling.
F_{CHR}	formal fate—fraction of used oil undergoing combustion with heat recovery (CHR).
F_{CD}	formal fate—fraction of used oil undergoing combustion for disposal (CD).
$F_{Landfill}$	formal fate—fraction of used oil being disposed in a landfill.

Emission factors will carry the unit of kg CO_2/kg.

EF_{CC}	complete combustion emission factor (all embedded carbon released as CO_2).
$EF_{recycle}$	emission factor for recycling of used oil.

EF_{CHR} emission factor for combustion of used oil with heat recovery.

EF_{CD} emission factor for combustion of used oil for disposal.

$EF_{Landfill}$ emission factor for disposal of used oil in landfill.

Shown below are possible application scenarios of the generic formula provided above.

Figure B.1 shows the visual representation of the formula shown above, in the scenario where the lubricant is completely based on fossil carbon. This is drawn as a Sankey diagram, analogous to Figure 3.

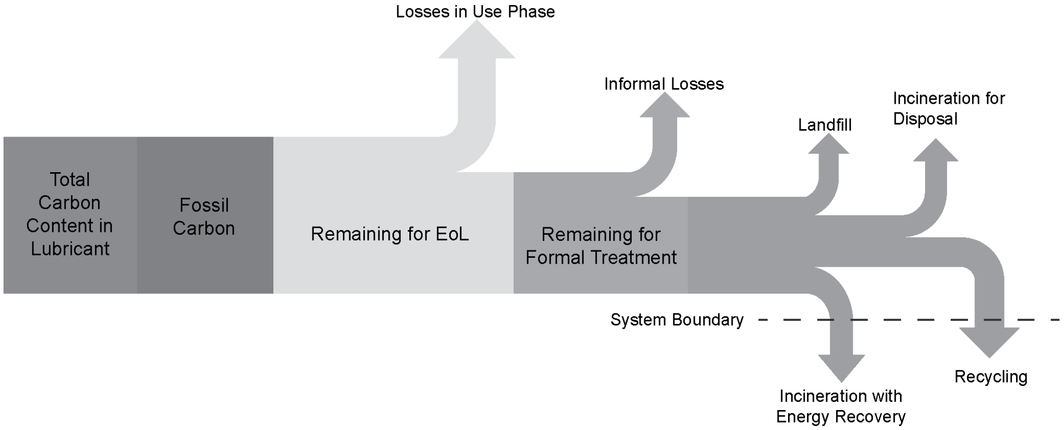


Figure B.1—Sankey Diagram for the "In Use" and "End-of-Life" Stages of the Life Cycle for a Product Based on 100 % Fossil Carbon

B.1 Example of a Two-cycle Oil

All lubricant is combusted as part of the intended application in the "in use" stage of the life cycle.

The formula simplifies as follows:

$$Contribution\ to\ CFP = EF_{CC}$$

This is as $MF_{use} = 1$, so all material has been accounted for, meaning $MF_{EoL} = 0$ and associated terms disappear from the formula.

The Sankey diagram for this scenario is shown in Figure B.2.

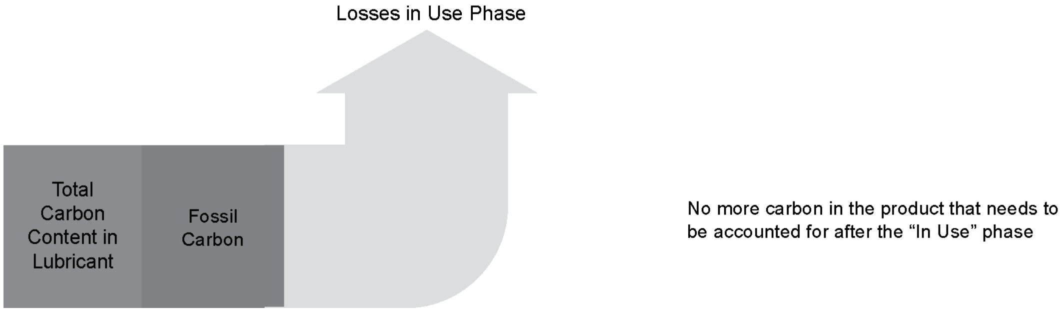


Figure B.2—Sankey Diagram for a Two-cycle Oil Product Based on 100 % Fossil Carbon

B.2 Example of Lubricant with 100 % of Lubricant Collected for Recycling

The formula simplifies as follows:

$$Contribution\ to\ CFP = MF_{use} \times EF_{CC} +$$

$$MF_{EoL} \times F_{informal} \times EF_{CC} + MF_{EoL} \times F_{formal} \times (EF_{recycle})$$

If $F_{recycle} = 1$, this means F_{CHR}, F_{CD}, $F_{landfill}$ = 0 and associated terms disappear.

If all informal disposals are ruled out and all waste materials available after the “in use” stage are reaching the formal channel of recycling, the formula simplifies further to:

$$Contribution\ to\ CFP = MF_{use} \times EF_{CC} + MF_{EoL} \times EF_{recycle}$$

The Sankey diagram for this scenario is shown in Figure B.3.

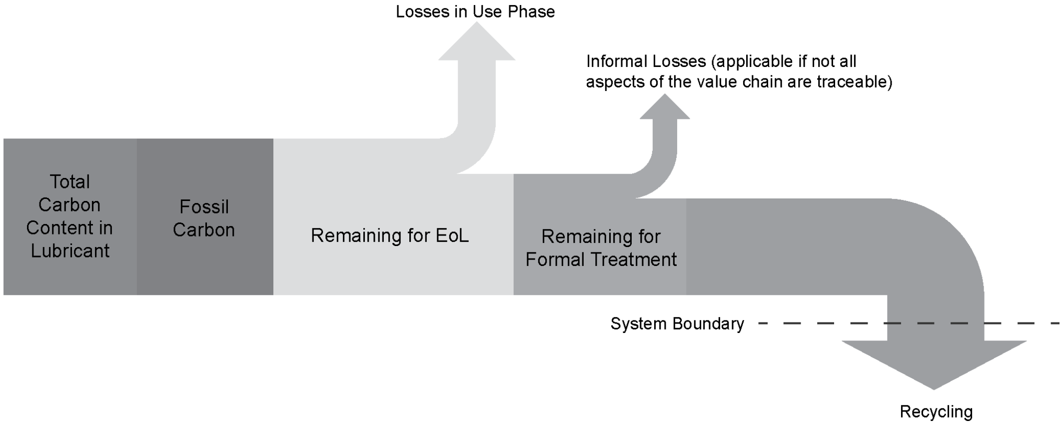


Figure B.3—Sankey Diagram for a Lubricant, Based on 100 % Fossil Carbon, with an End-of-Life Treatment of Complete Recycling

B.3 Example of Lubricant with 50 % of Biogenic Carbon Content

As defined in 5.5, the complete combustion factor (EF_{CC}) for a product based on both biogenic and fossil carbon is defined as follows:

$$EF_{CC}:\ kg\ CO_2/kg\ product = (\%total\ carbon \times (1 - \%biogenic\ carbon)) \times (mw_{CO_2}/mw_C)$$

If the product consists of 50 % biogenic carbon, this formula simplifies to:

$$EF_{CC}:\ kg\ CO_2/kg\ product = (\%total\ carbon \times 0.5) \times (mw_{CO_2}/mw_C)$$

Therefore, half of the total carbon content, which is not covered by a biogenic credit, still needs to have the contribution to the CFP during the “use” and “end-of-life” stages determined.

NOTE The biogenic carbon emissions should be reported separately.

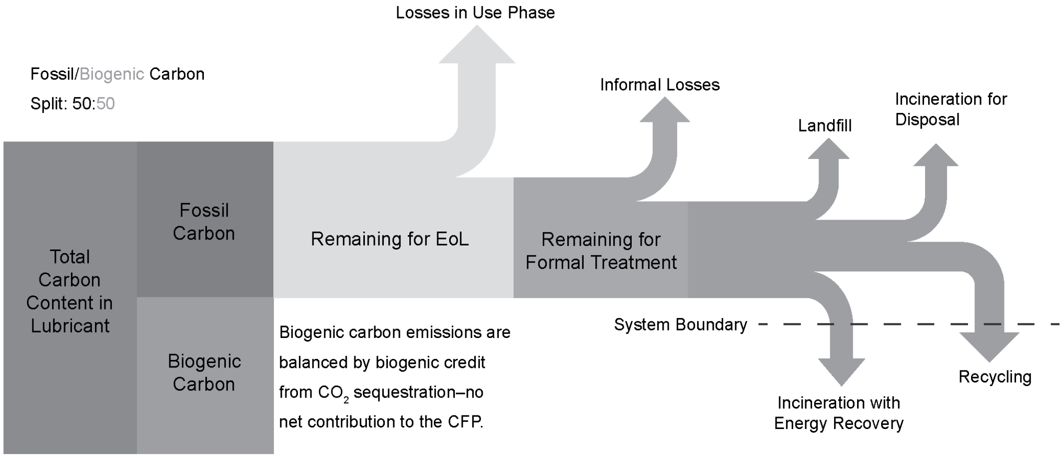
Applying the assumptions from 5.6.1 and the definition of EF_{CC} to the formula, the resulting formula for the contribution to the CFP is as follows:

$$Contribution\ to\ CFP = MF_{use} \times (\%total\ carbon \times 0.5) \times (mw_{CO_2}/mw_C) +$$

$$MF_{EoL} \times F_{informal} \times (\%total\ carbon \times 0.5) \times \left(mw_{CO_2}/mw_C\right) +$$

$$MF_{EoL} \times F_{formal} \times \left(F_{CD} \times (\%total\ carbon \times 0.5) \times \left(mw_{CO_2}/mw_C\right) + F_{landfill} \times (\%total\ carbon \times 0.5) \times \left(mw_{CO_2}/mw_C\right)\right)$$

The Sankey diagram for this scenario is shown in Figure B.4.



NOTE The biogenic carbon emission should be reported separately.

Figure B.4—Sankey Diagram for a Lubricant, Based on 50 % Biogenic Carbon, with Remaining Fossil Carbon Contributing to the "In Use" and "End-of-Life" Stages of the Life Cycle of the CFP

B.4 Numerical Example for Calculation with Formula

The assumptions are as follows:

— Ten percent of lubricant is lost to combustion in the "in use" stage.

— EF_{CC} is 2.93 kg CO_2/kg lubricant based on a carbon content of 80 % in the lubricant.

— Informal losses are assumed at 25 %.

— Half the material is recycled and half is combusted for purpose of disposal.

— The cut-off approach is applied.

$$\begin{aligned}&Contribution\ to\ CFP = 0.1 \times 2.93\ kg\ CO_2/kg\ lubricant + \\ &0.9 \times 0.25 \times 2.93\ kg\ CO_2/kg\ lubricant + \\ &0.9 \times 0.75 \times \left(0.5 \times 0\ kg\ CO_2/kg\ lubricant + 0.5 \times 2.93\ kg\ CO_2\ lubricant\right) = \\ &1.94\ kg\ CO_2/kg\ lubricant\end{aligned}$$

Annex C
(informative)

Alternative Treatment Approaches of “Combustion of Used Oil with Heat Recovery”

According to this technical report, a cut-off approach for the used oil fate of “combustion of used oil with heat recovery” shall be used. Other treatment approaches that might be encountered are shown below but are not recommended by this technical report.

If alignment with proposed approaches in Europe is desired, an alternative approach could be to share the associated emissions burden between the life cycle assessment for the lubricant product and the downstream beneficiary of the energy use. If transport emissions associated with the pickup fall to the downstream beneficiary, the associated emission factor would become $EF_{CHR} = ½ \times EF_{CC}$. To avoid double counting of the emissions associated with the embedded carbon in the product when using this approach, it needs to be communicated to the downstream beneficiary, that only half of the combustion emissions need to be accounted for.

Another approach that could apply to this used lubricants fate is to fully account for the associated combustion emissions (therefore application of EF_{CC}) as part of the life cycle assessment, but to balance these emissions with an emissions credit for the energy sources that are displaced. For this approach, it should be considered that from a practical perspective it can be challenging to identify what the fuel mix is that has been displaced in various applications by the used oil combustion.

But for limited applications of the methodology, where such data is available, this approach could be considered. The applicable emission factor would become $EF_{CHR} = EF_{CC} – EF_{C\ redit}$, where $EF_{C\ redit}$ is the sum of emissions that are associated with the displaced fuel mix.

Annex D
(informative)

Considerations on the Production Stage (Section 5.2)

Section 5.2 specifies the data that needs to be collected from a Lubricant Blending Plant (LBP), to assess the contribution to the CFP.

Additional details that can contribute to consumption of energy and, therefore, production of emissions at the asset are provided in the following points:

Blend Components

Lubricant blending plants operate in such a way as to assemble raw materials into sellable products. The three broad classes of components most likely to be encountered in such operations are:

— base oil(s) and/or base stocks;

— additives;

— packaging materials.

Base Oils and Base Stocks

These products are largely consumed due to their inherent viscosity. On arriving at the blend plant, especially in bulk, that inherent viscosity may preclude easy dispensing from the inbound vehicle to onsite storage. A frequent means of minimizing this hindrance is to apply heat to the container. For example, many bulk delivery truck wagons (and railcars) are designed with an outer jacket. The space between the outer jacket and the inner tank is lined with coils. Since many industrial plants generate and/or have access to high-pressure steam, a steam line is frequently connected to the inbound truck's coils to heat the inbound base oil (or base stock). On heating, viscosity generally decreases, so pumpability is enhanced. The means by which the steam (or other form of heat) is generated and applied in the base oil offloading process should be assessed regarding GHG emissions.

Additionally, once offloaded (commonly into a tank), bulk base oil will tend to return to ambient temperature. As with delivery vehicles, base oil storage tanks are frequently designed with steam coils to either constantly or intermittently apply heat to the tank's contents, thus making pumping operations easier. Again, the means and energy intensity of steam generation applied in such storage and pumping modes must be evaluated. If means other than steam are employed to warm a storage tank's contents, their energy intensity must also be evaluated. These considerations are especially significant in Nordic climates.

If received in drums or IBCs, base oils are likely to be moved to storage using mechanical devices such as cranes or forklifts. Many forklifts are powered by compressed natural gas, though in some locations the forklifts are battery-operated. The energy consumption of the equipment should be reviewed and evaluated, and the means of disposal of drums and/or IBCs after use must be evaluated.

Additives

As with base oils, the means and distance of transport, offloading, and disposal of waste packaging should also be assessed for energy intensity and emissions.

Packaging Materials

Most packaging materials are palletized for transport, so the distance traveled, as well as forklift and/or crane operations, must be assessed at time of receipt. Additionally, most palletized packaging features secondary packaging, commonly involving polymeric film wrap and/or securing the packaging with straps (metallic or polymeric). The nature and fate of this secondary packaging should be investigated.

Labels

When performed offsite, production of labels (including environmental impact of subcomponents like ink/pigments and energy requirements of production) and transport to the packaging site should be accounted for. In parallel, onsite spray-on application of labels should be assessed for emissions and energy intensity. The environmental impact of labels (e.g. hindrance on recycling) should be considered, whether the labels are sprayed or glued. Section 5.1.3 details considerations on packaging; as a special case if production of labels is onsite, the associated contribution should be included in the "production" section of the life cycle.

Blending

For liquid lubricants, the two key processes generally invoked are "batch" and "inline".

Batch processing generally involves combining formulation ingredients into a fixed receptacle, mixing the contents mechanically or using blown air, and transferring the ensuing mixture to storage (or directly to packaging operations). In some formulations, pre-treatment of additives is required, e.g. a drum of additive may be set in a heating cabinet overnight to allow its contents to become fluid enough for easy transfer into the mixing receptacle. The energy requirements of all these operations should be assessed. As one example, if a tank of bulk material has to be pre-heated just prior to mixing, the energy requirements of this operation should be accounted for.

Inline blending simultaneously injects the required liquid (or pre-dissolved) components into a mixing chamber, with only a brief residence time before transport to storage, packaging, or bulk loading. In this case, the components will frequently be constantly maintained at an elevated temperature in their respective storage tanks to ensure ready fluidity at time of mixing. The energy required for this constant heating of stored raw materials should be accounted for.

The manufacture of solid and semi-solid lubricants, such as greases, is often complex and process details are usually considered proprietary. However, since high-temperature kettles are frequently required to produce a grease, the energy requirements of these processes can be significant. For some publicly available insights, refer to the presentation by Dodos, et al. [27].

Line Flushing Operations

Most blending plants have segments of pipe traveled by two or more products. To minimize contamination between products traveling through these segments, two key strategies exist.

Flushing is an approach whereby the volume of product trapped in the line at a given moment is displaced by injecting a suitable quantity of the next product to be sent through the line. This injected quantity (and the residual amount of the first product) is usually treated as a waste stream. Common names for this waste stream include "flushings" and "line wash". The fate of these volumes of fluid should be assessed.

Additionally, it is frequently necessary to use flushing operations on packaging lines that package multiple product families.

The other strategy, commonly referred to as "pigging," involves mechanical displacement of the residual product in the line. The action is similar to that of a syringe: the pipe acts as the syringe's barrel, and a mechanically propelled oblong object (whose shape is somewhat reminiscent of a pig) operates as the plunger. While this process generates less waste fluid than flushing, implementing it requires capital expenditure, especially if it is adopted after the system is commissioned.

Storage—Bulk Product

After blending, bulk product may be stored with or without temperature control. If heating is constantly applied to maintain fluidity at all times, the energy requirements should be assessed. If heating is only intermittently applied, the power consumption should also be assessed since "spikes" and "troughs" in consumption may have different implications. In parallel, some bulk storage tanks have internal mixers to ensure homogeneity over time. Whether mixing is effected by a mechanical device or blown air, and applied constantly or intermittently, will affect energy consumption.

Storage—Packaged Product

The extent to which product must be discarded due to storage past its shelf life, the means of disposal (including disposal of packaging), and the use of any moving equipment (e.g. forklifts) should be part of the assessment.

Storage—Recovered Product

If a blending plant also operates a used-oil collection system, the energy/emissions details must be analyzed.

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