United States
Environmental Protection
Agency

EPA/600/R-19/092 | September 2019 | www.epa.gov/research

The Federal LCA Commons Elementary Flow List: Background, Approach, Description and Recommendations for Use

FEDERAL LCA COMMONS

Flowable	Context	Unit	Flow UUID
Phorate	emission/water/brackish water	kg	68b3da12-b6bd-3b29
Flubendiamide	emission/ground/human-dominate	kg	31f4f1db-58be-30c1
Chlorantranil	emission/water/fresh water	kg	4c80858e-5ae4-3abc
Octhilinone	emission/ground/terrestrial/sh	kg	a39674aa-8df2-3add
Acetamiprid	emission/water/saline water	kg	083667b9-5813-3cf7
Imazaquin,	emission/air	kg	73c460d5-35ef-3f74
(2E)-2-Hepten	emission/air/troposphere/rural	kg	fd688f18-2dcd-3a06
N-Benzyladeni	emission/air/troposphere/urban	kg	9c711a11-eb3a-32b5
Flavone	emission/water/subterranean/br	kg	2a30bd9e-ddb5-3a81
Caprolactam	emission/water/subterranean/br	kg	ece4afa4-331f-3135
Boron	emission/ground/terrestrial/ba	kg	6c8e4b09-3df1-3e56
Benzene,	emission/air/troposphere/very	kg	ffd48773-a713-3ce4
Poly(iminoimi	emission/water/fresh water	kg	fc86722d-4215-3436
Naphthalene,	emission/air/troposphere/urban	kg	35339a0a-92a3-3af1
Methylanthrac	emission/air/troposphere/urban	kg	d3b9d53f-ba88-3fd8
Furans,	emission/water	kg	bed8d84c-3984-3c5b
Ethylene	emission/air/stratosphere	kg	e650c1c0-4e37-3f5f
2,4-Dichloroa	emission/air/troposphere/rural	kg	3af8b87a-bc9a-31ff

Office of Research and Development
National Risk Management Research Laboratory
Land and Materials Management Division

Federal LCA Commons Elementary Flow List: Background, Approach, Description and Recommendations for Use

by

Ashley Edelen, Troy Hottle, Sarah Cashman
Eastern Research Group

Wesley Ingwersen
U.S. EPA/National Risk Management Research Laboratory/
Land and Materials Management Division

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Foreword

The U.S. Environmental Protection Agency (U.S. EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, U.S. EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) within the Office of Research and Development (ORD) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

Alice Gilliland, Acting Director
National Risk Management Research Laboratory

Abstract

Elementary flows are a foundational component of the life cycle assessment data model, used to represent resources and emissions that are used or released in human and industrial activities. They enable the development of life cycle inventories and the subsequent application of life cycle impact assessment methods to model potential impacts associated with product systems. This report describes the development of a standardized elementary flow list (FEDEFL) for the Federal LCA Commons. *Introduction* and *Background* sections describe relevant history of elementary flows in life cycle data, the purpose of a FEDEFL, and a technical background on elementary flows. An *Approach* section describes the steps toward creating the FEDEFL and mapping files to convert flows from other sources to FEDEFL flows. It includes the definition of flow classes and flow components - flowables, contexts, and units - and describes the assembly of the components into a flow list using a new Python package, *fedelemflowlist. fedelemflowlist* also provides the FEDEFL and mappings to Python users and creates a version of the list for use in openLCA software. A brief summary of the resulting v1.0 of the FEDEFL is provided in a *Summary* section, followed by general and flow class specific *Recommendations for Use*. Flows are anticipated to be regularly added to the FEDEFL to cover emerging life cycle data needs, and its functionality periodically enhanced as LCA modeling needs and capabilities continue to evolve. A system for updating the FEDEFL has been developed through GitHub and is described in *Future Work and Contributing*. Related files and resources including the FEDEFL on the Federal LCA Commons, the *fedelemflowlist* package and associated Wiki, and documentation of usage of the mapping files in openLCA software, are briefly described and links are provided. The FEDEFL will play a critical role in enabling interoperability between life cycle datasets created by federal agencies and can also serve as a standard for elementary flows for a broader community.

Acknowledgements

This report was developed as a part of the Federal LCA Commons Technical Working Group. This work included the consultation of different federal agency LCA subject matter experts and their support contractors.

Ezra Khan from the National Agricultural Library, USDA supported the development of ‘Biological’ flows with the National Agricultural Library glossary. Richard Bergman and ORISE Fellow Sveda Alanya-Rosenbaum at the US Forestry Service were also consulted on ‘Biological’ flows concerning the development of wood and forestry products.

In the development of the ‘Geological’ flows related fuels and ‘Energy’ terms, relationships and definitions, Michele Mutchek and Michelle Krynock, Key Logic contractors to DOE’s National Energy Technology Laboratory (NETL) provided valuable feedback and support for the development of the conversion factors and alternate units. In addition, Graham Lederer from USGS provided support for the structuring and development of non-fuel based ‘Geological’ terminology.

Jane Bare and Briana Niblick from the U.S. EPA along with Andrew Henderson as contract support for the DOD provided support for the structuring and development of the secondary flow context metadata that is supported by the TRACI 2.1 impact assessment method. Jane Bare also provided guidance and support for the structuring of the ‘Other’ flow class.

Ranjani Theregowanda as an ORISE Fellow with the U.S. EPA provided support for the structuring of the ‘Water’ flow class, primary flow context information associated with water environmental media and secondary flow class information associated with water bodies and aquatic features.

Other members of the Technical Working Group provided feedback related to use of earlier versions of the flow list in the LCA context, including Rebe Feraldi as contract support for DOE’s National Renewable Energy Laboratory, Michelle Krynock as contract support for NETL and Troy Hawkins from Argonne National Laboratory. Rebe Feraldi and Michelle Krynock also completed a thorough review of this report.

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Acronyms and Abbreviations

CAS	Chemical Abstracts Service
CEC	Commission for Environmental Cooperation
DADQ	Data Availability and Data Quality
DMR	Discharge Monitoring Report
DOE	United States Department of Energy
ECO	Earthster Core Ontology
EF	Elementary Flow
FEDEFL	Federal LCA Commons Elementary Flow List
GLAD	Global LCA Data Access initiative
HHV	Higher Heating Value
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
NALCMS	North American Land Change Monitoring System
NEI	National Emissions Inventory
NETL	National Energy Technology Laboratory
NPDES	National Pollution Discharge Elimination System
NREL	National Renewable Energy Laboratory
UNEP	United Nations Environment Programme
USDA	United States Department of Agriculture
ORISE	Oak Ridge Institute for Science and Education
RCRA	Resource Conservation and Recovery Act
SRS	Substance Registry Services
StEWI	Standardized Emissions and Waste Inventory
TRACI	Tool for Reduction and Assessment of Chemicals and other environmental Impacts
TRI	Toxic Release Inventory
TWG	Technical Working Group on Federal LCA Data Interoperability
UNEP/SETAC	United Nations Environment Programme/Society of Environmental Toxicology
USEPA	US Environmental Protection Agency
USGS	United States Geological Survey
UUID	Universally Unique Identifier
VOC	Volatile Organic Compounds

Chemical Symbols

CO_2	Carbon dioxide
N_2O	Dinitrogen oxide

1 Introduction

Organizations increasingly need to understand the environmental impacts of their products and processes so they can effectively target efforts to minimize environmental burdens and maximize resources. Life cycle assessment (LCA) provides a comprehensive 'cradle-to-grave' modeling method to determine the environmental impacts of goods or services. LCA is often used by organizations to compare environmental impacts of alternative product options on an equivalent basis and to ensure impacts are not simply shifted to upstream or downstream life cycle stages. While LCA can be a very powerful tool, it is data intensive and standardized methods are needed to combine data from multiple sources. Sources that LCA models are built from generally include a mix of existing databases and datasets that provide background life cycle inventory (LCI) data on energy, transportation and commodity materials coupled with primary data collected by the study team. Data sharing and exchange are also common practices in the LCA field, and standardized data formats are required to ensure no content is lost and no existing models are adversely affected during this transition. Significant efforts on LCA data sharing and interoperability have been made by the international community through the United Nations Environment Programme (UNEP) Life Cycle Initiative. Within the U.S., there are joint efforts between federal agencies such as the Federal LCA Commons to improve LCA data interoperability, while maintaining user autonomy through developments in database platform architecture and guidance for data quality management, metadata descriptors, and nomenclature (further described in Section 1.1). The objective of this project is to provide guidance on standard LCA nomenclature and its associated structure.

'Flows' are the essential components of data used for LCA. Flows may be of two broad types: elementary flows (EFs) or intermediate (known as "technosphere") flows according to the International Organization for Standardization (ISO) 14044 (ISO14044, 2006). EFs may be defined as materials, energy, or space that are taken directly from the environment or released directly back into the environment. EFs are the key flows in calculating final LCA results because they are the basis for impact assessment, while intermediate flows are used to connect flows within the full LCA model for the end goal of determining aggregate life cycle EF values per stage. Various conventions exist for naming (nomenclature), categorization, using, and storing EFs in LCA data, which causes inconsistencies in use and implementation of EFs when using data from multiple sources. This is both a problem for human readability and use, as well as a problem for machine management of these data in LCA software and databases, both of which are critical to LCA data interoperability. The focus of this work is, therefore, to develop a standardized EF structure and guidance for using this structure in LCA modeling across federal agencies.

1.1 Elementary flows in the global and U.S. contexts

The development of LCA methods and guidance materials and the information architecture supporting LCA has been driven by both international and national communities. This section offers a brief history of work related to EFs to better describe the historical developments that influenced the EF framework proposed in this guidance.

In 2002, the launching of the UNEP Life Cycle Initiative created an international platform under which organizations, scientists and government entities could cooperate to further contribute to LCA development. The publication the following year in 2003 of the Code of Life-Cycle Inventory Practice (de Beaufort-Langeveld, et al., 2003) distributed the collaborative guidance by five working groups. This included a recommended list of flows by the Data Availability and Data Quality (DADQ) working group. Desiring to preserve the autonomy of the user, the DADQ working group opted to provide a list of parameters with the preferred nomenclature. They also proposed a hierarchical concept for capturing additional flow information, or what this guidance calls flow context information (de Beaufort-Langeveld, et al., 2003). ISO has also guided the development of LCA through the ISO 14000 series. The ISO 14048 standard provides LCA nomenclature (ISO/TS 14048, 2002). In the 2000's, large LCI databases emerged, multiple LCA software tools were spawned, and LCIA methods proliferated, generally each using their own EF lists. Thus, despite the earlier guidance and international standards, a common universal flow list did not emerge.

In 2014, an intergovernmental group meeting regularly on LCA cooperation launched an initiative to create a global LCA network, called the Global LCA Data Access (GLAD) initiative. Data interoperability and exchange were established needs of GLAD. Three technical working groups were established as a part of the GLAD initiative: Network Architecture and Technology, Nomenclature, and Metadata Descriptors. As a part of the Nomenclature working group, a critical review of current EF usage was conducted and the resulting recommendations by Edelen et. al (2018) have been used as the foundation for this work. The analysis of EFs by Edelen et. al (2018) shows that there is still a need for further EF standardization to have machine readable, harmonized interoperable data for LCA.

On a parallel track, at the federal level within the U.S., there have also been significant developments within LCA. In 2014, technical LCA experts at federal agencies formed the Technical Working Group (TWG) on Federal LCA Data Interoperability to further discuss and collaborate on harmonization of LCA data and practice among U.S. government agencies. The group steers an initiative called the Federal LCA Commons, whose primary goal is to provide interoperable LCA data developed or sponsored by Federal agencies via a common data portal (US Department of Agriculture, US Environmental Protection Agency and US Department of Energy, 2018). The TWG is referred to herein as the Federal LCA Commons TWG or just TWG. The Federal LCA Commons portal[1] is now available and continues to grow and evolve (McCarthy & Cooper, 2012). The TWG tested whether LCI data from U.S. federal sources could be used together within standard LCA software. These tests revealed issues such as lack of common EFs that need to be overcome before federal LCI data is truly interoperable (Ingwersen, W.W., 2015). The TWG, defined as part of its annual work plan in 2017 and 2018 the

[1] Available at: http://www.lcacommons.gov/lca-collaboration (Accessed 8/2/19).

development of a common EF list to provide greater standardization and interoperability for federal LCA data.

1.2 Purpose

The main purpose of this report is to describe the creation of a common EF list for use in federal LCI and LCIA data (henceforth referred to as "FEDEFL"). The FEDEFL:

- Covers all elementary flows currently used and expected to be used in LCI and LCIA data for the Federal LCA Commons
- Uses terms and lists defined or adopted by authoritative U.S. or international sources
- Addresses problematic issues with existing EFs identified in Edelen et al. (2018)
- Structures and defines every term used
- Functions for use in the LCA software currently underlying the Federal LCA Commons data portal, openLCA
- Facilitates usage with existing LCA data through mappings from external source flows to FEDEFL flows
- Is created using a software package such that it can be regularly updated at intervals determined by the Federal LCA Commons technical working group

1.3 Relationship to other documents/resources

This document is supported by the following online repositories and documents:

1. A repository[2] for the *fedelemflowlist* Python package, management of the FEDEFL, and a documentation Wiki. *fedelemflowlist* is a Python 3.x package for generating the FEDEFL from the various input files and the flow mapping files described in this report and exporting those into a .zip archive of openLCA JSON-LD format files. The module allows Python users to access the FEDEFL and flow mappings for use in dynamic applications. The Federal LCA Commons community will use the GitHub functionalities associated with the repository to manage the FEDEFL, including providing updates and review of the input files, and creating releases for updates. See the Wiki[2] for more information.
2. The preferred flows are available via the Federal LCA Commons Data Portal[1] as part of the Federal LCA Commons Core Database. Instructions on how to use the FEDEFL to prepare LCA data for the Federal LCA Commons are included in the Data Submission Guidelines.

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[2] U.S. EPA GitHub Federal LCA Commons Elementary Flow List Repository. Available at: https://github.com/USEPA/Federal-LCA-Commons-Elementary-Flow-List/wiki (Accessed 8/2/19).

3. All terms found within the FEDEFL are defined within a vocabulary made available via the U.S. EPA Terminology Services[3] (U.S. EPA, 2019a) or within the U.S. EPA's Substance Registry Services[4] (U.S. EPA, 2019b).
4. The FEDEFL and mappings can be used in the open-source openLCA software[5] (GreenDelta, 2018). New functionality has been added in openLCA v1.9 to use the flow mappings to convert flows originally from other sources to the FEDEFL flows, if the user has source flows present in an openLCA database. A separate document[6] describes the use of this new functionality in openLCA.
5. The lciafmt[7] Python package can create LCIA methods that use the FEDEFL flows and write them to a .zip archive of openLCA JSON-LD for use in LCA software. As of finalization of this report, this package is still in development.

2 Background

This section provides a technical background on EF components, classification, nomenclature, and usage in LCA data and software.

2.1 Flow components

EFs must have three components to identify them (Edelen, et al., 2018):

1. **Flowable** - The name of the material, energy, or space (e.g., "Carbon dioxide" or "freshwater") that comes from or goes to the biosphere. This is commonly called "substance" or "flow name" but this term is too limited and the term "flowable" from the Earthster Core Ontology (ECO) is used in this report and in the FEDEFL (McBride & Norris, 2010).
2. **Context** - A set of environmental media/compartments that describe the flow origin or destination (e.g., "air"). Although the term compartment is sometimes used in LCA, the FEDEFL uses the term context to provide a broader meaning that includes the directionality (e.g. "resource" from biosphere or "emission" to biosphere), environmental media (e.g. "air", "water", "ground" and "biotic"), and additional context information that is further described in Section 3.3.

[3] U.S. EPA Terminology Services. Available at: https://iaspub.epa.gov/sor_internet/registry/termreg/searchandretrieve/termsandacronyms/search.do (Accessed 8/2/19).
[4] U.S. EPA Substance Registry Services. Available at: https://iaspub.epa.gov/sor_internet/registry/substreg/LandingPage.do (Accessed 8/2/19).
[5] openLCA software. Available at: http://www.openlca.org (Accessed 8/2/19).
[6] http://www.openlca.org/learning/
[7] LCIA formatter. https://github.com/usepa/LCIAformatter

3. **Unit** - Flow units may be associated with conversion factors that can be used to convert between different units within a flow property (e.g., kg to lbs.) or even between flow properties (e.g., kg to m^3).

Each of these individual flow components may be associated with more information, or metadata, in part dependent on what type of flow it is. For instance: flowables, if chemicals, may have a Chemical Abstracts Service number (CAS No.) and be associated with various other intrinsic properties. Other types of flows, like land use or energy inputs, may not have this additional information. Flows at a minimum should have a flowable, context and unit, and the unique combination of these components may be considered a unique flow, but whether or not it is unique has in practice been determined by the system in which it is used, such as the specific LCA software. Within LCA software, ID numbers are used to track unique flows and flow components. Such IDs are critical elements for identifying flows when incorporating them in LCA software. A universally unique identifier (UUID) is a common form of ID used in LCA data such as the Ecoinvent and GaBi databases and LCA software such as openLCA (GreenDelta, 2018).

2.2 Flow classes

Edelen et. al (2018) developed flow classes as an additional piece of flow metadata to improve the structure used to organize flows. Flow classes are a way to group EFs by their flowable type. Classes may have sets of contexts and units that distinguish them from flows in other classes. Table 1 is the original flow classification created by Edelen et. al (2018).

Table 1. Flow Class System from Edelen et. al (2018)

Type	Input / Output	Definition	Example Name(s)
Element or compound	Output	A unique chemical element or compound	1,1,2,2-Tetrachloroethane
Group of chemicals	Output	A group or mixture of chemicals	Volatile organic compounds, unspecified
Mineral, metal or aggregate	Input	A mineral or metal in an ore or aggregate material extracted for use or refining	Copper, 0.52% in sulfide, Cu 0.27% and Mo 8.2E-3% in crude ore, in ground
Biological	Input	Biomass or organic matter	Wood, hard, standing
Land	Input	Occupation of transformation of land	Occupation, arable, non-irrigated, diverse-intensive Transformation, from forest
Water	Both	Water	Water, well, in ground
Fossil or Nuclear Fuels	Input	A fuel source	Coal, hard, 20 MJ/kg
Energy	Input	Energy input not associated with materials	Energy, from geothermal
Other	Both	None of the above. May include water quality parameters; waste heat; solid waste; noise	Heat, waste BOD Solid waste

2.3 Flow nomenclature

Use of a common or easily shared nomenclature is a systematic way to provide consistent descriptors in scientific fields or other fields where data are organized and shared. A nomenclature is a system for naming entities within a realm of knowledge (Universty Press Oxford, 2016). Codified methods for the naming of flowables and contexts may be considered EF nomenclatures. Ideally, this common nomenclature would be used by all LCA data sources so names for flowables and contexts would be harmonized and easily corresponded across datasets.

The ISO 14048 standard provides LCA nomenclature guidance that also applies to EFs. ISO 14048 establishes three types of nomenclature: exclusive, inclusive, or user-defined (ISO/TS 14048, 2002). Exclusive nomenclature cannot be expanded by users as only specific terms are valid. ISO 14048 requires exclusive nomenclature for the directionality and receiving environment (compartment) for flows. Inclusive nomenclature may be expanded by the user when necessary for a specific application. ISO 14048 recommends that further receiving environment specification information be an inclusive nomenclature. User-defined nomenclature may be adapted as the user sees fit. The United Nations Environment Programme/Society of Environmental Toxicology (UNEP/SETAC) recommended list of parameters can be viewed as a user-defined nomenclature with guidelines (de Beaufort-Langeveld, et al., 2003).

A review of current EF nomenclature revealed that current guidance has been inadequate in addressing several types of challenges that contribute to duplicate and/or extraneous flows

(Edelen, et al., 2018). There may be discrepancies in application of the nomenclature resulting in differences in the names and contexts and minor differences such as extra spaces or commas. Lack of harmonization in application of a nomenclature causes disconnect between flows. As an example, one dataset may contain the use of a flow with the flowable "Nitrous oxide (N_2O)" while another may have a flowable with the name "Nitrous oxide", with otherwise the same contexts, units and metadata. These flowables refer to the same chemical (N_2O) but LCA software would interpret these as two independent flows. Furthermore, even "CO_2" and "CO2" may be identified as different entities due to use (or non-use) of subscripts.

2.4 Use in life cycle data and software

There are two main subparts of the LCA data model where EFs are used, LCI and life cycle impact assessment (LCIA). EFs are used in LCI to represent what is being exchanged between the biosphere and technosphere such as a raw resource (e.g., groundwater) consumed in a process and exchanges between the technosphere and biosphere with a process such as emissions of pollutants and other materials into the environment. LCIA methods enable the translation of uses of resources or releases in the environment into estimation of potential environmental impacts. EFs appear in LCIA method data, where flows are associated with characterization factors (units of impact per unit of flow) for estimating the potential impact of a given unit of a particular EF. The calculation of impact assessment results using data from an LCI (the fundamental accounting of a product system's EFs) and characterization factors from an LCIA method requires that the EFs in these LCA data model subparts correspond or match.

As data for LCI and LCIA are generally created by independent providers and LCA software developers create software to accommodate multiple LCI and LCIA sources, LCA software developers may develop their own lists of EFs, resulting in different sets of EFs being present in in all sources. EF matching between LCI and LCIA datasets in LCA software is not guaranteed. The responsibility for this EF matching across data sources within LCA software has been the unsaid responsibility of software providers, without external oversight or requirements for any documentation of validation of this flow matching and harmonization (Lesage, 2015).

The differences in EFs from these sources can create issues for LCA data exchange. If EFs are not identified by an authoritative ID that is used to identify an EF across all sources, and/or data exchange methods do not capture and use these unique IDs along with flow metadata, then EF identities or information will be lost in the data exchange.

3 Approach to Creation of the Flow List and Mappings

The approach to the creation of the FEDEFL builds on the recommendations of the GLAD network critical review Edelen et. al (2018), and incorporates the anticipated modeling needs of federal agencies participating in the Federal LCA Commons TWG. The steps for creating the FEDEFL include defining flow list components, creation of flow classes, definition of a flow nomenclature, development of flow contexts and units, selection of flowables, identification of preferred flows, and defining a method of flow list assembly. Experts were consulted throughout the process in order to obtain discipline-specific insight to structuring and naming flows for each flow class.

3.1 Flow components

A common list of flow list components and associated metadata was defined. Flowables, contexts, and units are the primary components of each flow. Flows are organized into classes. A flow as a whole may have an external reference like a URL, and must have a unique ID number. The development of these components is described in depth in the following sections.

3.2 Flow classes

The classification of flows allows for a more systematic approach to the creation of the FEDEFL. The initial classification system proposed by Edelen et. al (2018) was modified and a re-organization of the flows based on the newly proposed classification system is shown in Table 2.

The flow classes proposed by Edelen et. al (2018) are used with a minor change, the removal of the 'Fuels' class. It is the position of this guidance that classifications by the activity, such as a 'Fuels' class, should not be used and the nine-class system proposed by Edelen et. al (2018) has been updated to the following eight-class system.

Table 2. FEDEFL Flow Classification System

Flow Class	Input or Output	Definition	Common flow properties	Example Name(s)
Element or Compound	Both	A unique chemical element or compound	Mass	1,1,2,2-Tetrachloroethane
Groups of Chemicals	Output	A group or mixture of chemicals	Mass	Volatile organic compounds
Geological	Both	A mineral or metal in an ore or aggregate material extracted for use or refining[a]	Mass or Energy	Anthracite
Biological	Both	Input: Biomass or organic matter[a]	Mass	Hardwood
		Output: biological matter (e.g. microorganisms, animal dander, house dust, mites and pollen)	Mass	Bacillus Subtilis

Flow Class	Input or Output	Definition	Common flow properties	Example Name(s)
Land use	Input	Land types	Area*time	Forest
Water	Both	Water[a]	Mass	Water, fresh
Energy	Input	Energy input **NOT** associated with **consumed** materials including heat	Energy	Energy, Geothermal
Other	Both	None of the above. May include water quality parameters; solid waste		Biological Oxygen Demand Total Organic Carbon

[a] All materials that can be used as fuels, such as crude oil, coal, wood, biomass, etc. and water flows include a default conversion factor for an alternate unit (i.e., 'Anthracite' has a default conversion factor from mass to energy or 'Freshwater' has a conversion factor mass to volume). Further recommendations for appropriate usage of conversion factors within LCA can be found in section

3.3 Flow contexts

Flow context is divided into two parts, primary and secondary. Primary context information includes the flow directionality (resource or emission) and environmental media (air, water, ground or biotic). A flow is required to have both primary context compartment classes to be included into the FEDEFL. Secondary context information consists of eight compartment classes arranged in the following hierarchical structure (See Figure 1). Human-dominated and Terrestrial are also considered compartment classes even though they exist under the Land class. Secondary context information is not applicable to all flow classes; however, recommended or preferred secondary flow context information has been established for each of the different flow classes. Secondary flow context information by compartment is shown for each flow class + primary flow context (directionality + environmental media). Each flow class + primary flow context can have more than one preferred set of secondary context information. For example, chemical emissions to air have secondary primary context information for outdoor emissions and indoor emissions. Initially, the environmental media compartment was limited to three compartments; air, water and ground. However, when discussing ‘Biological’ flows the environmental media from which these types of flow originate is not adequately addressed by these terms and the term biotic was included as an environmental media.

Flow Class	Flowable	Flow Context (Primary)
Biological	Hardwood	Resource, biotic
Biological	Biomass	Resource, biotic

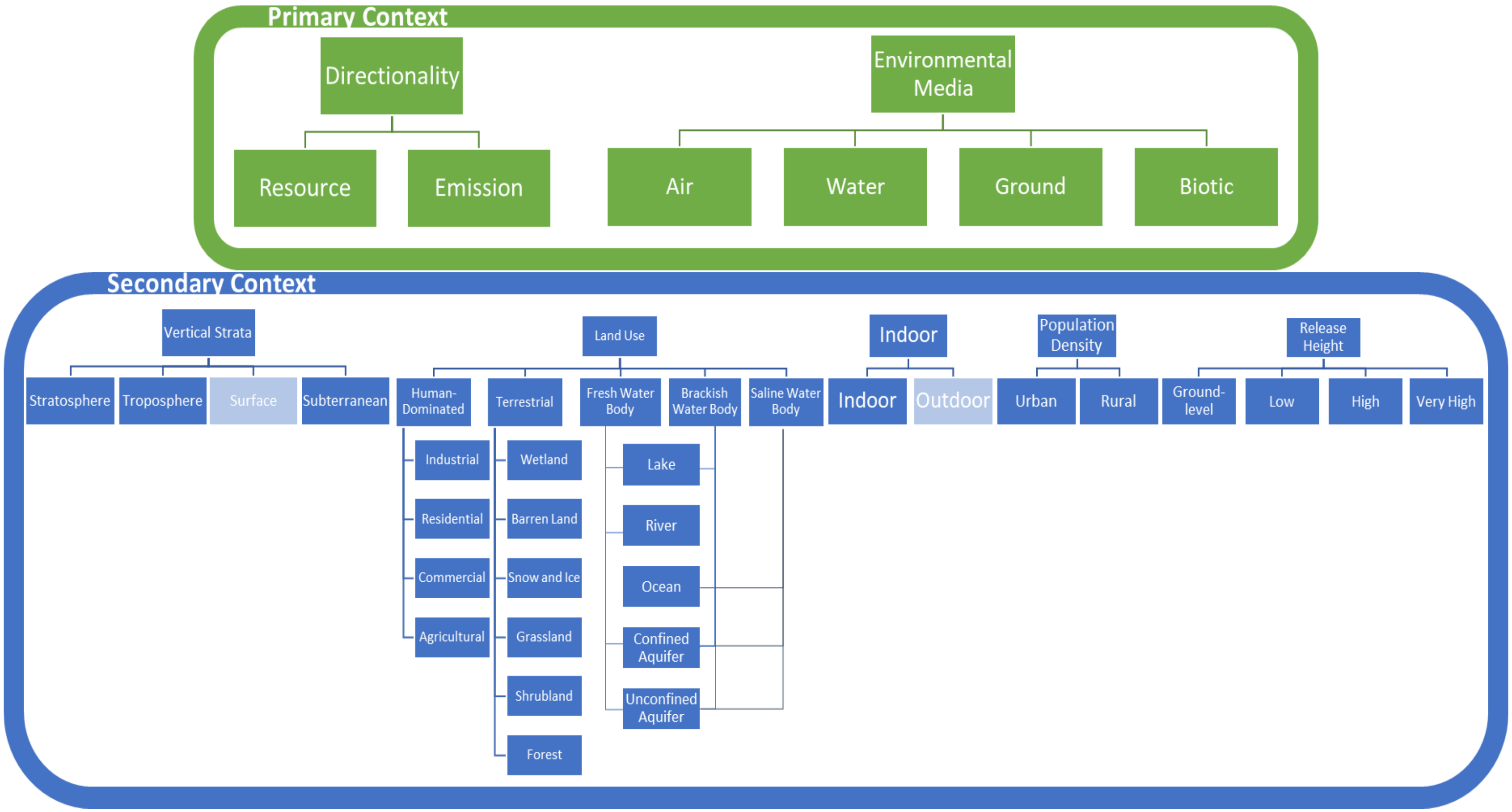

Figure 1. Compartment classification of primary and secondary flow context.

Previously, the environmental media compartments were used not only to refer to the environmental media, but also the vertical strata of a flow. For example, a resource flow from a groundwater well would have conventionally had ground as the media. However, ground more accurately describes the vertical strata from which the resource is extracted, while the environmental media from which the resource is flowing is water. Therefore, in the FEDEFL the terms air, water and ground refer to the media, while another compartment class is used to describe the vertical strata. This is the first time these two compartment classes are used to clarify the difference between environmental media and vertical strata. Primary context information is not detailed enough to adequately capture the necessary information to connect LCI data to LCIA methods; therefore, based on LCA practitioner feedback, the secondary context information was developed.

A new approach for the secondary context information was used for the classification of land use. The nomenclature of land use context is based on the North American Land Change Monitoring System (NALCMS), but simplified for LCA use as some terms were overly specific and not applicable to current LCA data. This system was chosen because it uses land cover in development of the nomenclature. The structure of the land use compartment class provides additional clarity by distinguishing water body types from land use types, as waterbodies are not land. Land use compartment classes are separated by human dominated and natural land cover types. In addition, the novel concept of addressing waterbody types by salinity is introduced.

Vertical strata as a compartment class is introduced to further clarify the difference between environmental medias and vertical strata. Also, the new atmospheric terms in the vertical strata compartment class allow for LCA emissions outside of the troposphere to be included. Any emissions not assigned a specific vertical stratum are by default considered to be emissions at the earth’s surface level.

The release height compartment class is based on LCIA nomenclature specifying the height of emissions to air within the troposphere. Stack heights are defined as <25m, ≥25 to 150m, and >150m for low, high, and very high, respectively (Humbert, et al., 2011) (U.S. GAO, 2011). The indoor compartment class consists of only one compartment, while all other emissions not assigned the indoor compartment are assumed to be outdoors. The default release height is ground-level and the release height compartment should only be used for situations where stack height is known.

The population density compartment class is based on the population per square mile found in (Humbert, et al., 2011). ‘Urban’ is defined as an area with a population density of >390 people per square kilometer or >1000 people per square mile, and ‘rural’ as areas with lower population density. Users should be aware that the definitions offered by Humbert, et al. (2011) differ from those used by the U.S. Census Bureau (US Census Bureau, 2018).

3.4 Flow units

A reference unit is defined for each flowable. SI units are used exclusively for all units. As a source of units, the FEDEFL uses a more recent list of units in openLCA software (GreenDelta, 2018). For those flowables that may have more than one property (e.g. ‘Mass’, ‘Volume’), an alternate flow unit is declared, along with a default conversion factors in the form of alternate unit per reference unit.

3.4.1 Flow unit conversions

As stated above, certain flows may have more than one property, which requires flow unit conversion. For example, geological flowables that are used as fuels require a conversion factor from mass to energy or water flowables may need to be converted from mass to volume depending on use. Default conversion factors are sourced from federal data sources or other data sources when federal reference values are not available.

3.5 Flow nomenclature

This work used the nomenclature framework established by ISO 14048, Section 7.1, to build the proposed EF nomenclature found within this guidance (ISO/TS 14048, 2002).

The FEDEFL master list increases the clarity of the individual flow and metadata components associated with a flow by not only clearly defining the components, but also by applying the ISO 14048 series types of nomenclature to each of the flow and metadata components. As described previously, there are three types of nomenclature; exclusive, inclusive and user defined. The nomenclature type of flow components in the FEDEFL is defined in Figure 2.

The CAS No. and the chemical formula are defined and maintained by an external source and thus considered an externally-defined inclusive nomenclature. The FEDEFL framework applies the concept of exclusive nomenclature to the flow class, flow property, primary context, and corresponding UUIDs. For each of these components a predetermined and defined set of terms has been provided. For example, the directionality of a flow can only be ‘Resource’ or ‘Emission’ no other terms are acceptable. Due to the exclusive nature of the flow class, flow property and primary context the UUIDs for each of these components are also exclusive. The elementary flowables, the secondary context, and unit converters are all considered inclusive nomenclature that will be managed by the Federal LCA Commons. The flow list version identifier will also be an inclusive nomenclature managed by the Federal LCA Commons. The description and synonyms are not structured or controlled at this time and are therefore, user defined nomenclatures.

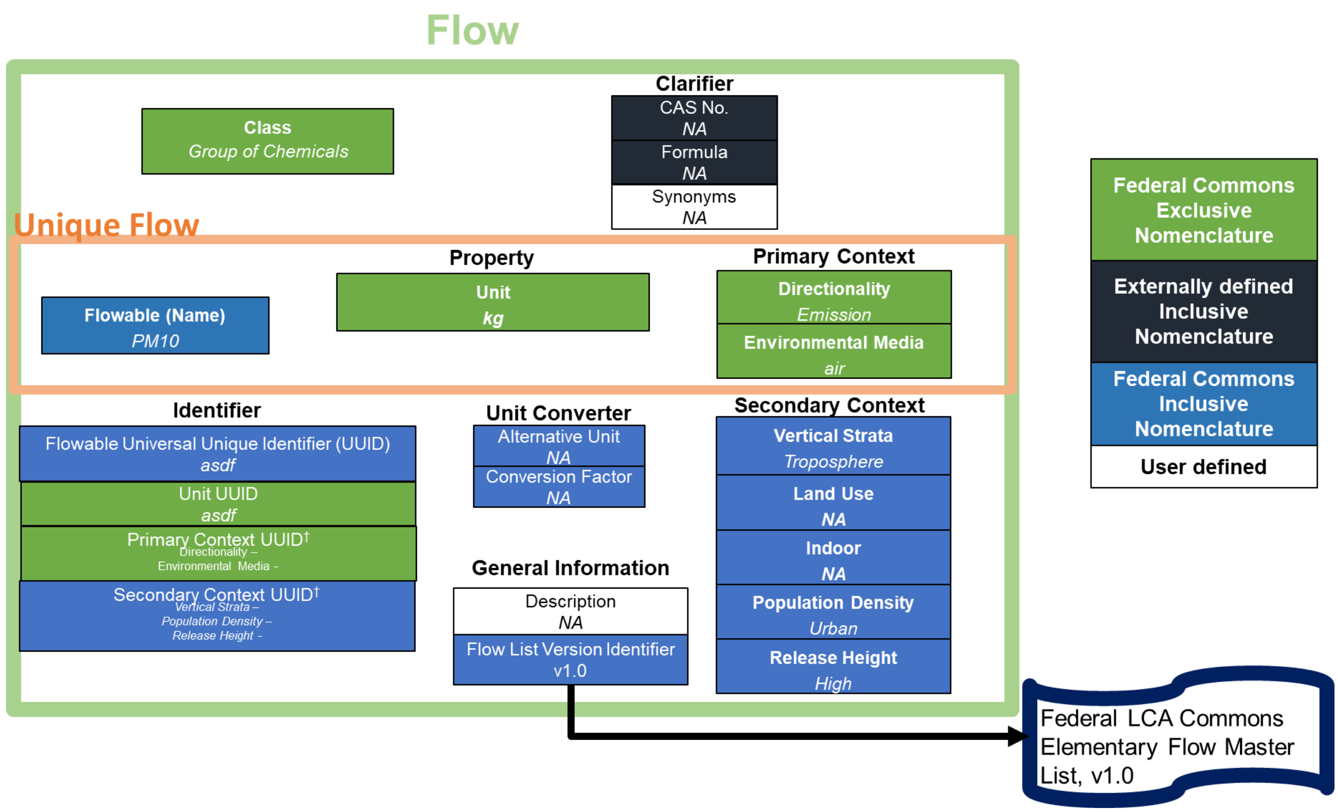

Figure 2. Defining the nomenclature type of flow components.

3.5.1 Context nomenclature

Flow class, flow context directionality and environmental media are defined as exclusive nomenclatures and are therefore limited to the terms as described in Section 3.3. However, additional flow context information is considered an inclusive nomenclature and is expected to be adapted over time as new developments within LCIA methods occur and new terms are needed.

3.6 Flowables

Edelen et. al (2018) showed that 'Elements or Compounds' or 'Groups of Chemicals' make up the majority of EFs. The flow list classification revealed a major design difference in the 'Elements or Compounds' and 'Groups of Chemicals' classes versus the other six flow classes. It was decided that a different approach would be taken for the creation of the 'Elements or Chemicals' and 'Groups of Chemicals' flowables. Flows classified as non-chemicals were derived from the data collected from the Edelen et. al (2018) critical review. These flows were used as a guideline for the determination of flowables for the non-chemical classes and includes flowables from different LCI, LCIA and LCA software resources. Subject matter experts across relevant federal agencies were also consulted when generating the non-chemical flowables list. As described in the subsequent section, relevant EPA data sources were used to generate the flowables list for 'Elements or Compounds' or 'Groups of Chemicals'.

Additional metadata are used to provide additional information on each flowable. These include CAS No., chemical formulas and synonyms. Not all metadata are relevant for all flow classes; these metadata are valid for Chemicals and Groups of Chemicals, but only synonyms are relevant for the remaining flow classes.

3.6.1 Element or Compound and Groups of Chemicals

To eliminate duplication of 'Element or Compound' (aka 'Chemicals') and 'Groups of Chemicals' a systematic approach was taken to collect flowable names from federal emission and LCA sources. The following sources were utilized to collect chemical names:

- **TRI** – Toxic Release Inventory. The TRI is a publicly available emission data for industrial facilities that are either from a specific industry (all federal facilities must report if they meet the other two criteria), employ 10 or more full-time employees; manufactures, processes or otherwise uses a TRI-listed chemical[8] (U.S. EPA, 2019c).
- **NEI** – National Emissions Inventory. The NEI[9] (U.S. EPA, 2019d) is an estimate of criteria pollutants, criteria precursors, and hazardous air pollutants built using the Emissions Inventory System[10] (U.S. EPA, 2019e) to collect and blend data from State, Local, and Tribal air agencies and updated every three years.
- **RCRA** – Resource Conservation and Recovery Act. RCRA is a EPA reporting program to track non-hazardous solid waste[11] (U.S. EPA, 2019f) and hazardous solid waste[12] (U.S. EPA, 2019g) from 'cradle-to-grave' that requires large quantity generators to report every two years.
- **DMR**- Discharge Monitoring Report. The National Pollution Discharge Elimination System[13] (U.S. EPA, 2019h) (NPDES) permit for point source discharges to water sources, that provide publicly accessible data. DMR is the periodic (monthly, seasonally or semi-annual) water pollution reports submitted to NPDES by industries, municipalities, and facilities that discharge to surface waters.
- **eGRID** – Emissions & Generation Resource Integrated Database[14] is a data source for air emissions and generation of electrical power in the U.S. (U.S. EPA, 2019i).

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[8] U.S. EPA Toxic Release Inventory. Available at: https://www.epa.gov/toxics-release-inventory-tri-program/tri-listed-chemicals (Accessed 8/2/19).
[9] U.S. EPA National Emissions Inventory. Available at: https://www3.epa.gov/enviro/facts/nei/ (Accessed 8/2/19).
[10] U.S. EPA Emissions Inventory System: https://www.epa.gov/air-emissions-inventories/emissions-inventory-system-eis-gateway (Accessed 8/2/19).
[11] U.S. EPA Resource Conservation and Recovery Act Non-Hazardous Waste. Available at: https://www.epa.gov/rcra/resource-conservation-and-recovery-act-rcra-regulations#nonhaz (Accessed 8/2/19).
[12] U.S. EPA Resource Conservation and Recovery Act Hazardous Waste. https://www.epa.gov/rcra/resource-conservation-and-recovery-act-rcra-regulations#haz (Accessed 8/2/19).
[13] U.S. EPA National Pollutant Discharge Elimination System. Available at: https://www.epa.gov/npdes (Accessed 8/2/19).
[14] U.S. EPA Emissions & Generation Resource integrated Database. Available at: https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid (Accessed 8/2/19).

- **TRACI** – Tool for Reduction and Assessment of Chemicals and other environmental Impacts[15] (TRACI) is an environmental impact assessment tool for characterization of life cycle data (Bare, 2011).
- **openLCA** – is a free open source life cycle assessment software developed by GreenDelta (GreenDelta, 2018).

The automated StEWI module developed by EPA was used to generate lists of flows used in U.S. EPA datasets (U.S. EPA, 2018). Once chemicals were collected from these sources, chemicals were defined using two U.S. EPA chemical databases, the Substance Registry Services (SRS)[16] and the Chemistry Dashboard[17]. SRS is the EPA's authoritative resource on chemicals, biological organism and other substances tracked and regulated by EPA. The Chemistry Dashboard is a database for chemistry, toxicity and exposure information for over 760,000 chemicals. The EPA chemical databases were used to match chemical names, CAS No., and chemical formulas. SRS names are used in preference over chemistry dashboard naming. A common naming system for flows, allows for the removal of duplicates and the correspondence of many sources of flowables and contexts to the FEDEFL.

Additionally, EPA sources are used for defining what chemicals are included in each of the 'Groups of Chemicals'. Any 'Groups of Chemicals' flowables that were unidentifiable or non-chemicals, such as, 'Panthalium' or 'Triorganostannate', were removed from the list. 'Groups of Chemicals' are further curated by splitting the list into preferred and non-preferred. Preferred 'Groups of Chemicals' are flowables that are linked to impacts from the TRACI 2.1, ReCiPe (Huijbregts, 2016) or ImpactWorld+ (Bulle, 2019) LCIA methods or the openLCA software (GreenDelta, 2018).

3.6.2 Biological

The 'Biological' flow class addresses three types of flowables: biological materials most often used as fuels, wood and biomass, raw resources for forestry products (e.g. wood) and biological emissions such as microorganisms. Wood flowables in LCA are used for two main purposes, to describe wood that will eventually be used as fuel and wood that will be used as forestry products like flooring and/or construction material and each of these activities requires different information about the wood. Wood flowables that are used to describe wood for fuel requires information about the energy content of the wood and are much less concerned with the type of wood. Therefore, a default conversion factor for wood is provided to convert between the default

[15] U.S. EPA Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts. Available at: https://www.epa.gov/chemical-research/tool-reduction-and-assessment-chemicals-and-other-environmental-impacts-traci (Accessed 8/2/19).
[16] U.S. EPA Substance Registry Services. Available at: https://ofmpub.epa.gov/sor_internet/registry/substreg/LandingPage.do (Accessed 8/2/19).
[17] U.S. EPA Chemistry Dashboard. Available at: https://comptox.epa.gov/dashboard (Accessed 8/2/19).

units in mass (kg) to energy (MJ). Based on feedback from the U.S. Forestry Services, flowables for forestry products are most often classified as 'softwood' or 'hardwood'.

Biomass has two main activities associated with its use, fuel and soil amendment/fertilizer. Biomass' association with fuel activities has a default conversion factor for the flowable. This conversion factor is an average higher heating value (HHV) of the energy content of three types of biomass, forest residue (dry basis), 15.40 MJ/kg; herbaceous biomass, 17.21 MJ/kg; and corn stover 16.37 MJ/kg (Argonne National Laboratory, 2010).

The U.S. Department of Agriculture (USDA) LCI includes the flowables for microorganism emissions to soil and therefore these flowables are included in the FEDEFL.

3.6.3 Energy

The 'Energy' type is defined as energy inputs not associated with a consumed material (e.g. solar, geothermal, wind and hydropower) and energy emissions to the environment in the form of heat. Therefore, for energy to be considered an EF resource, it must be from a renewable source.

There are different types of hydropower, including that derived from rivers and offshore sources such as tidal (below surface and driven by the gravitational pull of the moon) and wave (on the surface derived from the wind blowing across the surface of the ocean). However, naming of the flowables is not affected by the activity used to collect the energy. Any additional information on the type of collection can be included in the general information of the flow.

3.6.4 Geological

'Geological' flowables refer to substances that come from the earth's crust. This class includes minerals, ores, rocks and aggregates, and non-renewable fuels (e.g. natural gas, coal, methane, etc.). 'Geological' have a unit of 'kg' except for the fuels, which have a default value of 'MJ'. The fuels also contain conversion factors between 'MJ' and 'kg'. The conversion factors utilize the HHV of fuels.

3.6.5 Land

To simplify and clarify land use flowables, a single term 'land use' is used as the flowable and all additional information about the land cover is addressed using the secondary context information.

The critical review by Edelen et. al (2018) revealed two main types of 'Land' flowables, land occupation and land transformation. Current usage of land transformation flows provides incomplete information as it describes either the land before transformation or the land after transformation, but never both. For example, 'transformation to cropland', only describes the product of the transformation, but not the original land. It is the perspective of the authors that land transformation is not a flow, but rather an activity and land flowables should describe the land cover.

To simplify the land flowables, all land cover types are used as part of the flow context information. Therefore, the 'Land' class contains only one flowable, 'land use'.

3.6.6 Other

The 'Other' class consists of a variety of flowables that do not easily fit within the definitions of the other seven flow classes. For the FEDEFL v1.0, only water quality parameters (e.g., Biological oxygen demand, Total organic carbon) are included in this category

3.6.7 Water

The critical review by Edelen et. al (2018) revealed that the water nomenclature is inconsistent. The first step to providing a consistent nomenclature was to organize and structure the important water properties. Five properties emerged from the study; salinity (e.g. freshwater, brackish or saline), water feature (e.g. lake, river, ocean, etc.), vertical strata (e.g. ground, surface or atmospheric), location and activity (e.g. drinking, municipal, irrigation, etc.). As previously stated, activities should not be captured as a part of a flowable as they are not inherent properties of a flow but describe how the flow is utilized within a process. The location is also a property of a process and not an individual flow. Therefore, there are three main properties of water that are needed to be captured by a flow in the FEDEFL. The FEDEFL captures the water feature and vertical strata within the flow context, and the nomenclature for 'Water' flowables are based solely on the salinity.

3.7 Flow mapping

The uniform naming convention of the flowables enables the tracking and translation of flowable characteristics from disparate databases through a consistent and reproducible process. Utilizing the databases referenced in Section 3.6, flowables were mapped to the two primary compartment classes, directionality and environmental media.

Directionality specifies whether flowables interact with the environment as a 'resource' being extracted, 'emission' being released, or both. Flowables present in LCIA methods were assumed to be emissions while those present in LCI or other datasets had to be evaluated for eligibility in the 'resource' and 'emission' categories. All of the flowables in the Chemicals, Groups, and Other classes were designated 'emission', while the flow classes, 'Geological' and 'Land' contain only 'resource' flowables. The remaining flow classes, 'Biological', 'Energy', and 'Water' include flowables for both designations.

The flowables were also associated with the environmental media they flow to or from. The options for environmental media are 'air', 'ground', 'water', and 'biotic', which are the primary context categories (see Section 3.3). This context mapping is based on the scope of the source database. For the federal datasets, NEI and eGRID flows are only associated with the 'emission/air' context, which is mapped in parallel with the flowables. TRI enables reporting of emissions to all three primary contexts (air, water, and ground) and the flowables combined with the relevant context are mapped together. TRACI 2.1, which is an aggregation of impact assessment calculations for chemical flows, uses a two-step approach. First the list of all the FEDEFL flowables were mapped back to TRACI (where applicable) to ensure full correspondence. The FEDEFL contexts are designed to enable nested contextual hierarchies allowing for the mapping of TRACI and other LCIA methods. The context mapping file assigned all compartment combination possibilities to the flowables within TRACI. Each flowable and context combination within the completed FEDEFL list is assigned a unique UUID.

The records from the reference datasets were assigned a match condition based on the relationship between the source datasets and the condensed, uniform list of FEDEFL flowables. Most dataset entries had a direct correspondence to the flowables in FEDEFL were designated as such. However, for some records only a portion of the potential flowable and are set as ‘<’ the FEDEFL flowable. Likewise, some dataset records are aggregated compared to the FEDEFL flowables and were designated as ‘>’ relative to the flowable specified in the FEDEFL.

As a product of the Federal LCA Commons TWG, the development of mapping files is focused on providing mappings from Federal sources including NEI, TRI, TRACI, and eGRID to the FEDEFL.

Mappings are designed to match flows using the match conditions. Match conditions may be 'equal to', 'a superset of', 'a subset of', or ‘a proxy for'.

Narrower match conditions may be used in situations where sources use a group flowable when the FEDEFL would recommend the use of individual flowables, such as with chemical mixtures as seen in Table 3. Broader match conditions are used when source flowable names contain overly specific information that do not map to an impact characterization and therefore are mapped to broader terms, as seen in Table 3.

Table 3. Flowable Mapping with Match Condition Examples

Source Flowable	Match Condition	Target Flowable
Iron mixt. with manganese	>	Manganese
Iron mixt. with manganese	>	Iron
Pentane, perfluoro-, mixt with perfluorohexane	>	Perfluoropentane
Pentane, perfluoro-, mixt with perfluorohexane	>	Perfluorohexane
PM25-Primary from certain diesel engines	<	Particulate matter - PM2.5

Mappings include not only flowable mappings, but mappings of the flow units and flow context information. Mappings are required for units if sources units differ from the FEDEFL default units. Unless flow context nomenclature is the same as that used by the FEDEFL, flow context mapping is also required.

3.8 Flow preference

Recalling the first purpose of the FEDEFL (to cover all elementary flows), the lists of flowables and contexts are designed to be comprehensive. While flowables are intended to be unique and should not be duplicated in the FEDEFL, they are not all defined with the same authority, or may be less desirable to use in LCA data because they are by nature less precisely defined. For examples, groups of chemicals in general do not define the chemical constituents and percentage composition. In general, preferred flowables are those with more precise definitions.

The contexts, on the other hand, include intentional redundancies, with varying levels of environmental context specification. For example, a content may exist with only a primary context, like 'emission/air', and another context with the same primary context but with secondary context compartments, like 'emission/air/ troposphere/low'. The same flowable may appear in both of these contexts, as well as additional contexts with the same primary context and perhaps some of the same secondary context compartments. In general, preferred contexts are those with more precise environmental compartment information in the secondary context.

For these reasons, the FEDEFL may have a number of flows with redundant information, although in totality, each flow will be unique. To provide more direction in selection of flows, the term 'preferred flow' is used to describe flows within the FEDEFL that have both preferred flowable and preferred context information. This flow designation has implications for flow presence in releases and flow usage, which are discussed later. The full list of flows FEDEFL is also referred to as the 'Master' list.

3.9 Flow list assembly

To construct the FEDEFL, flowable, contexts, units, and supporting metadata were compiled into standardized tables to be used as inputs. Standard formats were defined for Flowables, FlowablePrimaryContexts, and FlowableAltUnits to be populated for each class of flows, as well as for SecondaryContextMembership and Contexts, of which one table of each is created for the FEDEFL. The standard formats are all defined in the github repository under format specs.

The Contexts data list all possible contexts for flows. The SecondaryContextMembership file defines which context patterns are to be associated with flows based on their class and primary contexts. A context pattern is hierarchical set of the primary and secondary context classes. For any given context pattern, there are one or more contexts defined.

The input data are assembled into a list by combining each Flowable file with FlowablePrimaryContexts to create records for each Flowable and PrimaryContext combinations. Alternate units were added to the records when present for a flowable in FlowableAltUnits. SecondaryContextMembership is used to then assign a list of all context patterns to each Flowable and PrimaryContext combination. Flows are then created for each Flowable and Primary Context using all Contexts matching the context pattern assigned to that Flowable and PrimaryContext combination. UUIDs are then assigned as unique IDs to each flow. If the Flowable is marked as preferred in Flowables, and the Context pattern in

SecondaryContextMembership is marked as preferred for that flow class and Flowable and PrimaryContext combination, then the flow is designated as a Preferred Flow.

These data were used as inputs into Python scripts that combine these input files to assemble the master flow list. The assemble script (flowlist.py) and supporting script (contexts.py), as well as the flow list default variables (in globals.py), are incorporated into the *fedelemflowlist* Python package. *fedelemflowlist* allows a Python user to retrieve the flow list and mapping files in the standard formats, and writes selected flows and mappings out to a .zip archive of JSON-LD file matching the openLCA schema. More information can be found in the README file and the Wiki. Installation instructions for the *fedelemflowlist* Python module are available on the GitHub repository. The *fedelemflowlist* can export files conforming to the JSON-LD openLCA schema. LCA practitioners can then use the FEDEFL directly within the openLCA software. OpenLCA also allows for flows to be exported in other common formats used by different software programs such as ILCD and Ecospold.

A series of pass/fail style test scripts were created to validate the input and outputs of *fedelemflowlist*. A test script was created to check that all input files are compliant with the input format specifications, the flow list specification, and to assure that flowables are unique. Additional tests were created to validate the created flow list and the flow mapping files. Another script tests that valid JSON-LD files are created from a flow list and mapping files. Each of these tests were run and 100% of tests passed before creation of v1.0 of the FEDEFL.

4 Summary of the Flow List, v1.0

Version 1.0 of the FEDEFL was generated using the *fedelemflowlist* Python package using input files created using the methods described in the previous section. The overall structure of v1.0 of the FEDEFL as it will appear to users within an LCA software package is based on the flow classification previously defined in Figure 1. This section provides an overview of v1.0 of the FEDEFL.

Counts of unique flowables in the FEDEFL are presented in Table 4. All contexts present in the FEDEFL are listed in Table A-1 in Appendix A. There are 114 unique contexts, 63 for emissions and 51 for resources.

Table 4. Flowable Summary for FEDEFL v1.0

Class	No. of Flowables	Percent of Flowables
Biological	9	0.18%
Chemicals	4395	85.86%
Energy	5	0.10%
Geological	460	8.99%
Groups	241	4.71%
Land	1	0.02%
Other	4	0.08%
Water	4	0.08%
TOTAL	5,119	

A summary of the flows – which are a combination of the flowables and the context designated for that flowable – in the FEDEFL v1.0 is provided in Table 5. The total number of flows in the list is 238,485. Approximately half of those flows are preferred flows.

Table 5. Flow Summary for FEDEFL v1.0.

Class	No. of Flows	No. of Preferred Flows	Percent of Flows
Biological	9	7	0.00%
Chemicals	227,895	129,378	95.56%
Energy	7	7	0.00%
Geological	947	679	0.40%
Groups	9,273	1,728	3.89%
Land	31	20	0.01%
Other	5	5	0.00%
Water	318	128	0.13%
TOTAL	238,485	131,952	

5 Recommendations for Use

The FEDEFL was developed to serve as the standardized elementary flow list for the Federal LCA Commons. The FEDEFL is publicly available and can also be used more widely by LCA practitioners, LCI data developers, and LCIA modelers with an interest in employing a systematic approach to LCA nomenclature. The following section provides general guidance on how to utilize the FEDEFL.

5.1 General guidance

Usage of the FEDEFL can be applied to new LCI unit processes or LCIA methods. The FEDEFL can also be implemented in existing LCI and LCIA data.

This guidance document does not specify the scope of LCI or LCIA datasets. However, when the scope is defined in a way that involves modeling of exchanges between the biosphere and technosphere and the intention is to use the FEDEFL, some or all of these recommendations apply, depending on what types of exchanges are modeled (e.g. land use, energy flows, pollutant emissions) and the corresponding elementary flow classes that are used.

For LCA modeling where the FEDEFL is used in LCI, the use of LCIA methods that have been mapped to the FEDEFL is recommended. Combined use of the FEDEFL common nomenclature in LCI unit processes and LCIA methods will ensure LCI flows are not inadvertently left out of LCIA results that should be capturing these flows. For a tool that can generate LCIA methods with the FEDEFL flow, see the *lciafmt* in Relationship to other documents/resources. For LCI modeling, practitioners should ensure the FEDEFL is applied consistently across all unit processes in the product life cycle model.

The subsequent sections provide more detail on usage of the FEDEFL for new or existing LCA data. If data are being developed to comply with the Federal LCA Commons Data Submission Guidelines, defer to those guidelines for application of the FEDEFL.

5.1.1 General guidance for new life cycle data

- In developing new LCI and LCIA data, selecting flows from among the preferred flows (see Flow preference for an explanation of preferred flows) is recommended. The flow description specifies whether the flow is preferred or not.

- The flowables included in the preferred flows may serve as a guideline to the types of materials, energy, and occupation of space information to be collected when beginning to construct an LCA model. The preferred flows indicate the flowable reference unit. Alternative units with standardized conversion factors are also available for flowables where data may be collected on different unit bases. For example, geological flowable inputs to the LCI can be collected on either a mass or energy basis.

- The contexts of the preferred flows can also be used as a suggested guideline for the collection of elementary flow data during the inventory development. For example, as 'emission/ground/human-dominated/agricultural/rural' is a preferred context for chemical releases to ground, inventory data should ideally be collected with this full context information that includes this land use, as opposed to using only the ''emission/ground' context. Preferred contexts should also be used for determining the contexts for which LCIA factors need to be developed. Using the contexts of preferred flows from the FEDEFL at the onset of LCI or LCIA data collection and data development will help to ensure that an appropriate level of detail is captured by the LCA practitioner when building the model. It will also ensure that the level of detail between LCI and LCIA correspond.

- If users are developing LCI or LCIA within LCA software, the users should have the preferred flows loaded into the LCA software before creating the LCI, to be sure they are using the elementary flow objects from the FEDEFL. If using the FEDEFL within openLCA, users should load the FEDEFL into a new database that contains units and flow properties, but not complete reference data. Note that attempting to manually recreate the elementary flows in the FEDEFL in the LCA software will not result in flows matching those in the list.

- For LCI creation, it is important that users adhere to the strict definition of elementary flows versus product flows[18], as an elementary flow must transition from or to the biosphere without any additional treatment or transformation. If any treatment or transformation occurs, this should be represented by one or more additional processes. This general rule still presents some limitations. The FEDEFL does not include waste material flows that escape the treatment process (litter). More research is required to model these flows effectively in LCA and these flows cannot be modeled as elementary flows with v1.0 of the FEDEFL. The FEDEFL is also not intended to provide guidance on product flow nomenclature.

- Elementary flows in the FEDEFL do not have specific locations associated with them, like states, countries, or watersheds. Location data should be part of LCI process inventory data, as process metadata, and not part of the elementary flow. If LCIA factors are developed for specific locations for elementary flows, LCA software can group elementary flows in LCI by location and apply selected impact factors, as is done in openLCA.[19]

5.1.2 General guidance for existing LCA data

For existing LCA datasets, the recommended approach is to use or develop a flow mapping to the FEDEFL and apply that mapping. New mappings can be developed within the *fedelemflowlist* package (See Flow list assembly for a description of this package*)*. See Future Work and Contributing for a link to instructions on how to create mappings. Once these mappings are present within the *fedelemflowlist* package, they can be written to JSON-LD along

[18] See ISO 14044 (2006), 4.2.3.3.2.

[19] See Regionalized LCIA in openLCA. http://www.openlca.org/wp-content/uploads/2016/08/Regionalized-LCIA-in-openLCA.pdf

with the corresponding flows, and imported into openLCA software, where they can be applied to existing LCA data in an openLCA database. See the Relationship to other documents/resources for a link to documentation describing this procedure. For application of the mappings to LCI being generated in an automated manner that can use the *fedelemflowlist* Python package, the mappings can be applied to convert flows more directly. It should be noted that FEDEFL flows that are *mapped to* in flow mappings may not be preferred flows because the source flows do not have the flowable or context detail that corresponds to a preferred flow.

5.2 Class specific usage

This section provides guidance on the structure of the eight classes within the FEDEFL.

5.2.1 Biological

'Biological' flows are used to represent all living organisms that are extracted from the biosphere (i.e., resources) or bacteria and viruses emitted to the biosphere (i.e., emission). The terms recommended for this flow class exclude the usage of specific wood species. It is recommended that if a specific species of wood is necessary, that the use of The Wood Database[20] Wood Finder be used, and the common names captured in the flowable synonyms (Meier, 2008-2019). Use of more specific 'Biological' flows such as hardwood or softwood are preferred over a more generic flow such as wood or biomass. Biomass is considered by the FEDEFL as a group since biomass materials are comprised of aggregated organic components such as cellulose, hemicellulose, and lignin. It is important for users of the term biomass to be aware of the great variations in content with biomass. If biomass is used to represent an energy source, it is recommended that the default conversion factors provided in the FEDEFL are used and users provide scenario specific energy content when necessary. It is also recommended that users exercise caution when using the term biomass as a soil amendment or fertilizer because the nutrient content of biomass is variable based on material type. This class is not intended to represent biological waste material flows.

5.2.2 Element or Compound (aka 'Chemicals')

'Element or Compound' flowables are chemical emissions to air, water or ground. It is important to note that unless a chemical name is identifiable it cannot properly connect with an LCIA method. When using chemicals, it is important to collect additional metadata on the chemicals you wish to include in your LCI or LCIA in order to identify corresponding flows in the FEDEFL. Particularly the CAS number can be used for identification, as CAS are available for most Element or Compound flowables in the FEDEFL. Chemicals should not be used as inputs unless they occur naturally and are directly extracted from the biosphere without further processing.

[20] The Wood Database. Available at: https://www.wood-database.com/wood-finder/ (Accessed 8/2/19).

5.2.3 Energy

All energy sources associated with materials are addressed under either the 'Geological' type, such as anthracite coal or the 'Biological' type, such as wood. The term 'Energy' is used in combination with the source (e.g. Energy, geothermal). This class includes energy directly extracted from the biosphere such as solar, wind, geothermal and hydro energy. Heat is only considered an energy emission. Heat generated from power is not an elementary flow but rather a technosphere flow (i.e. product flow). The flowable geothermal energy should be used to represent heat from the earth as a resource.

5.2.4 Geological

'Geological' flows can be classified as resources and emissions. However, for emissions, it is preferred to use chemical names and not mineral names to improve LCIA. Non-fuel 'Geological' terms are defined using the mineral database, mindata.org (Hudson Institute of Mineralogy, 2019). This database provides information on the minerals including appearance, associated minerals, and common locations of occurrence. Often in LCIs, terms such as 'aluminum ore' are used. These non-specific descriptions are discouraged. To help users avoid using generic 'ore', guidance on associated minerals is provided in Table 6. The selection of individual flows with the associated minerals as flowables is recommended in this case. Metadata on the 'Geological' flows is available within the FEDEFL, including the CAS No., chemical formula, and synonyms as applicable.

Table 6. Guidance for Common Associated Minerals

Ores	Associated Mineral	Associated Mineral 2	Associated Mineral 3	Associated Mineral 4	Associated Mineral 5	Associated Mineral 6
Aluminum ore	Bauxite					
Arsenic ore	Arsenopyrite					
Bismuth ore	Bismite	Bismuthinite				
Cadmium ore	Greenockite	Smithsonite	Sphalerite			
Caesium ore	Pollucite					
Chromium ore	Chromite	Magnesiochromite				
Cobalt ore	Carrollite	Heterogenite	Erythrite	Glaucodot	Cobaltite	
Cobalt ore	Linnaeite	Safflorite	Skutterudite	Azurite	Bornite	
Copper ore	Chalcocite	Chalcopyrite	Covellite	Cuprite	Copper	Malachite
Copper ore	Tennantite	Tenorite	Tetrahedrite			
Copper carbonate ore	Azurite	Malachite				
Copper oxide ore	Cuprite	Tenorite				
Copper sulfide ore	Bornite	Tetrahedrite	Chalcopyrite	Covellite	Tennantite	Chalcocite
Gold ore	Gold					
Iron ore	Goethite	Hematite	Limonite	Maghemite	Magnetite	Marcasite
Iron ore	Pyrite	Siderite				

Ores	Associated Mineral	Associated Mineral 2	Associated Mineral 3	Associated Mineral 4	Associated Mineral 5	Associated Mineral 6
Iron oxide ore	Goethite	Hematite	Magnetite			
Iron sulfide ore	Marcasite	Pyrite	Pyrrhotite			
Lead ore	Anglesite	Cerussite	Galena			
Lithium ore	Lithium salt ore	Lithium silicate ore				
Lithium salt ore						
Lithium silicate ore	Hectorite	Lepidolite	Petalite	Spodumene		
Mercury ore	Mercury	Cinnabar	Calomel			
Nickel ore	Nickel laterite	Nickel sulfide ore				
Nickel laterite						
Nickel sulfide ore						
Silver ore	Silver	Galena	Acathite			
Sulfide ore	Nickel sulfide ore	Copper sulfide ore	Iron sulfide ore			
Tin ore						

Users should be cautious when using conversion factors for fuels. The conversion factors can be based on the HHV of the refined fuel and not be a true reflection of the energy content of the raw material at extraction. Applying a heating value for a fuel that is a reflection of the combustion ready material can miss the mass loss that occurs between during the refining process between extraction and combustion of a fuel. If a HHV of the refined fuel is used and there is a mass loss between extraction and combustion then it is recommended that a ~5-10% (estimated average) loss of energy be accounted for in order to have an accurate cumulative energy demand. This loss does not apply to fuels where there is no mass loss from extraction to combustion.

5.2.5 Groups of Chemicals

It is recommended that when dealing with mixtures of chemicals, the individual chemicals or compounds are used in combination within a unit process to improve the reliability of impact results. 'Element or Compound' flowables are, therefore, recommended over 'Groups of Chemicals' whenever possible as several 'Groups of Chemicals' names do not correspond to LCIA methods. In the absence of more specific information on the individual chemical constituents, the FEDEFL provides elementary flows to capture such groups. Certain group emissions such as Particulate matter, > 2.5µm and ≤ 10µm, nitrogen oxides, volatile organic compounds (VOCs), and phosphorus compounds are accounted for in LCIA methods. If a user knows the total amount of, for example, VOCs, and only a portion of the speciated VOC chemicals, it is recommended for the user to first use the speciated VOCs from the chemicals list and then only the VOC group to represent any of the mass of VOCs not accounted for by the speciated chemicals.

5.2.6 Land

'Land' flowables should be used in conjunction with a land product flow to represent land transformations. A land product flow should consist of the 'Land' flowable representing the original land cover (as a positive input) and the 'Land' flowable representing the final land cover (as a negative input). A carbon dioxide emission can account for the carbon dioxide release associated with the land change. The process model should include any materials, energy, or transportation required during the land transformation process as well. There is only one 'Land' flowable in v1.0 of the FEDEFL, 'land use', which has a unit of m^2*a (square meters*years), while the land cover types are included as context information

5.2.7 Other

Similar to 'Groups', flows in the 'Other' class should only be used when more detailed information on chemical composition is unknown. It is recommended that specific chemicals are used to specify emissions when available, rather than water quality measures. As mentioned in the previous section, v1.0 of the FEDEFL does not include waste material flows that escape the treatment process (litter).

5.2.8 Water

The 'Water' class should be used to represent the physical flow of water by weight (preferred) or by volume into (resource) or out of (emission) a unit process. It is recommended that the user pick a water flow with specific characteristics such as fresh, brackish, and saline. A more generic water flow is provided if such details are unavailable for the flow. Properties of water are different than 'Water' flows. In the FEDEFL water properties such as biological or chemical oxygen demand are categorized in the 'Other' flow class (see Other). It is also important to avoid terms such as 'moisture.' The water class flows are not designed for modeling moisture in biomass or other flows.

6 Future Work and Contributing

The FEDEFL is intended to be a living list that is improved upon over time as it is used by developers of data for the Federal LCA Commons and more widely by LCA practitioners. The list is open to contributions from all members of the LCA community. More information on the submission guidelines for additions to the FEDEFL are found in the Contributing section of the GitHub repository wiki. Users can recommend additions to the FEDEFL. The two primary manners of contributing to the FEDEFL are by adding to the flow list and creating and editing flow mapping files.

Aside from adding to or editing the FEDEFL flows and flow mappings, functional enhancements may be needed in the future to accommodate new functionality in LCA modeling. Enhancements that could be made include defining nested substances for flows. For example, the 'Wood' flow could further be defined by the cellulose, hemicellulose, and lignin content. Alternatively, the group flow 'Particulate matter, ≤ 2.5 µm' could be speciated to its chemical constituents based on sector profiles. Developing a more granular flow list will only practically matter for LCA modeling if this level of detail is also implemented in LCI and LCIA modeling as well as in LCA software. These different components of LCA modeling need to continue to evolve in parallel to ensure full interoperability of datasets between federal agencies and the FEDEFL will serve as a platform to enable those linkages with respect to elementary flows in LCA data.

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Appendix A – Supporting Tables

Table A-1. Contexts in FEDEFL and indication of use for flows by class.

Context	Biological	Chemicals	Energy	Geological	Groups	Land	Other	Water
emission/air	0	1	1	0	1	0	0	1
emission/air/indoor	0	1	0	0	1	0	0	1
emission/air/stratosphere	0	1	0	0	1	0	0	1
emission/air/subterranean	0	1	0	0	1	0	0	1
emission/air/troposphere/ground-level	0	1	0	0	1	0	0	1
emission/air/troposphere/high	0	1	0	0	1	0	0	1
emission/air/troposphere/low	0	1	0	0	1	0	0	1
emission/air/troposphere/rural	0	1	0	0	1	0	0	1
emission/air/troposphere/rural/ground-level	0	1	0	0	1	0	0	1
emission/air/troposphere/rural/high	0	1	0	0	1	0	0	1
emission/air/troposphere/rural/low	0	1	0	0	1	0	0	1
emission/air/troposphere/rural/very high	0	1	0	0	1	0	0	1
emission/air/troposphere/urban	0	1	0	0	1	0	0	1
emission/air/troposphere/urban/ground-level	0	1	0	0	1	0	0	1
emission/air/troposphere/urban/high	0	1	0	0	1	0	0	1
emission/air/troposphere/urban/low	0	1	0	0	1	0	0	1
emission/air/troposphere/urban/very high	0	1	0	0	1	0	0	1
emission/air/troposphere/very high	0	1	0	0	1	0	0	1
emission/ground	1	1	1	1	1	0	1	1

Context	Biological	Chemicals	Energy	Geological	Groups	Land	Other	Water
emission/ground/human-dominated	0	1	0	0	1	0	0	1
emission/ground/human-dominated/agricultural	0	1	0	0	1	0	0	1
emission/ground/human-dominated/agricultural/rural	0	1	0	0	1	0	0	1
emission/ground/human-dominated/agricultural/urban	0	1	0	0	1	0	0	1
emission/ground/human-dominated/commercial	0	1	0	0	1	0	0	1
emission/ground/human-dominated/commercial/rural	0	1	0	0	1	0	0	1
emission/ground/human-dominated/commercial/urban	0	1	0	0	1	0	0	1
emission/ground/human-dominated/industrial	0	1	0	0	1	0	0	1
emission/ground/human-dominated/industrial/rural	0	1	0	0	1	0	0	1
emission/ground/human-dominated/industrial/urban	0	1	0	0	1	0	0	1
emission/ground/human-dominated/residential	0	1	0	0	1	0	0	1
emission/ground/human-dominated/residential/rural	0	1	0	0	1	0	0	1
emission/ground/human-dominated/residential/urban	0	1	0	0	1	0	0	1
emission/ground/subterranean	0	1	0	1	1	0	0	1
emission/ground/terrestrial/barren land	0	1	0	0	1	0	0	1
emission/ground/terrestrial/forest	0	1	0	0	1	0	0	1
emission/ground/terrestrial/grassland	0	1	0	0	1	0	0	1
emission/ground/terrestrial/shrubland	0	1	0	0	1	0	0	1
emission/ground/terrestrial/snow and ice	0	1	0	0	1	0	0	1
emission/ground/terrestrial/wetland	0	1	0	0	1	0	0	1
emission/water	0	1	1	1	1	0	1	1
emission/water/brackish water body	0	1	0	0	1	0	0	1

Context	Biological	Chemicals	Energy	Geological	Groups	Land	Other	Water
emission/water/brackish water body/lake	0	1	0	0	1	0	0	1
emission/water/brackish water body/lake/rural	0	1	0	0	1	0	0	1
emission/water/brackish water body/lake/urban	0	1	0	0	1	0	0	1
emission/water/fresh water body	0	1	0	0	1	0	0	1
emission/water/fresh water body/lake	0	1	0	0	1	0	0	1
emission/water/fresh water body/lake/rural	0	1	0	0	1	0	0	1
emission/water/fresh water body/lake/urban	0	1	0	0	1	0	0	1
emission/water/fresh water body/river	0	1	0	0	1	0	0	1
emission/water/fresh water body/river/rural	0	1	0	0	1	0	0	1
emission/water/fresh water body/river/urban	0	1	0	0	1	0	0	1
emission/water/saline water body	0	1	0	0	1	0	0	1
emission/water/saline water body/ocean	0	1	0	0	1	0	0	1
emission/water/subterranean	0	1	0	1	1	0	0	1
emission/water/subterranean/brackish water body	0	1	0	0	1	0	0	1
emission/water/subterranean/brackish water body/confined aquifer	0	1	0	0	1	0	0	1
emission/water/subterranean/brackish water body/unconfined aquifer	0	1	0	0	1	0	0	1
emission/water/subterranean/fresh water body	0	1	0	0	1	0	0	1
emission/water/subterranean/fresh water body/confined aquifer	0	1	0	0	1	0	0	1
emission/water/subterranean/fresh water body/unconfined aquifer	0	1	0	0	1	0	0	1
emission/water/subterranean/saline water body	0	1	0	0	1	0	0	1
emission/water/subterranean/saline water body/confined aquifer	0	1	0	0	1	0	0	1

Context	Biological	Chemicals	Energy	Geological	Groups	Land	Other	Water
emission/water/subterranean/saline water body/unconfined aquifer	0	1	0	0	1	0	0	1
resource/air	0	0	1	1	0	0	0	1
resource/air/subterranean	0	0	0	1	0	0	0	1
resource/air/troposphere	0	0	0	1	0	0	0	1
resource/biotic	1	0	0	0	0	0	0	0
resource/ground	0	0	1	1	0	0	0	0
resource/ground/human-dominated	0	0	0	0	0	1	0	0
resource/ground/human-dominated/agricultural	0	0	0	0	0	1	0	0
resource/ground/human-dominated/agricultural/rural	0	0	0	0	0	1	0	0
resource/ground/human-dominated/agricultural/urban	0	0	0	0	0	1	0	0
resource/ground/human-dominated/commercial	0	0	0	0	0	1	0	0
resource/ground/human-dominated/commercial/rural	0	0	0	0	0	1	0	0
resource/ground/human-dominated/commercial/urban	0	0	0	0	0	1	0	0
resource/ground/human-dominated/industrial	0	0	0	0	0	1	0	0
resource/ground/human-dominated/industrial/rural	0	0	0	0	0	1	0	0
resource/ground/human-dominated/industrial/urban	0	0	0	0	0	1	0	0
resource/ground/human-dominated/residential	0	0	0	0	0	1	0	0
resource/ground/human-dominated/residential/rural	0	0	0	0	0	1	0	0
resource/ground/human-dominated/residential/urban	0	0	0	0	0	1	0	0
resource/ground/human-dominated/rural	0	0	0	0	0	1	0	0
resource/ground/human-dominated/urban	0	0	0	0	0	1	0	0
resource/ground/subterranean	0	0	0	1	0	0	0	0

Context	Biological	Chemicals	Energy	Geological	Groups	Land	Other	Water
resource/ground/terrestrial/barren land	0	0	0	0	0	1	0	0
resource/ground/terrestrial/forest	0	0	0	0	0	1	0	0
resource/ground/terrestrial/grassland	0	0	0	0	0	1	0	0
resource/ground/terrestrial/shrubland	0	0	0	0	0	1	0	0
resource/ground/terrestrial/snow and ice	0	0	0	0	0	1	0	0
resource/ground/terrestrial/wetland	0	0	0	0	0	1	0	0
resource/water	0	0	1	1	0	0	0	1
resource/water/brackish water body	0	0	0	0	0	0	0	1
resource/water/brackish water body/lake	0	0	0	0	0	1	0	1
resource/water/brackish water body/lake/rural	0	0	0	0	0	1	0	1
resource/water/brackish water body/lake/urban	0	0	0	0	0	1	0	1
resource/water/fresh water body	0	0	0	0	0	0	0	1
resource/water/fresh water body/lake	0	0	0	0	0	1	0	1
resource/water/fresh water body/lake/rural	0	0	0	0	0	1	0	1
resource/water/fresh water body/lake/urban	0	0	0	0	0	1	0	1
resource/water/fresh water body/river	0	0	0	0	0	1	0	1
resource/water/fresh water body/river/rural	0	0	0	0	0	1	0	1
resource/water/fresh water body/river/urban	0	0	0	0	0	1	0	1
resource/water/saline water body	0	0	0	0	0	0	0	1
resource/water/saline water body/ocean	0	0	0	0	0	1	0	1
resource/water/subterranean	0	0	0	1	0	0	0	1
resource/water/subterranean/brackish water body	0	0	0	0	0	0	0	1
resource/water/subterranean/brackish water body/confined aquifer	0	0	0	0	0	0	0	1

Context	Biological	Chemicals	Energy	Geological	Groups	Land	Other	Water
resource/water/subterranean/brackish water body/unconfined aquifer	0	0	0	0	0	0	0	1
resource/water/subterranean/fresh water body	0	0	0	0	0	0	0	1
resource/water/subterranean/fresh water body/confined aquifer	0	0	0	0	0	0	0	1
resource/water/subterranean/fresh water body/unconfined aquifer	0	0	0	0	0	0	0	1
resource/water/subterranean/saline water body	0	0	0	0	0	0	0	1
resource/water/subterranean/saline water body/confined aquifer	0	0	0	0	0	0	0	1
resource/water/subterranean/saline water body/unconfined aquifer	0	0	0	0	0	0	0	1

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