Department of Defense Guidance

Streamlined Life Cycle Assessment Process for Evaluating Sustainability in DoD Acquisitions

10 August 2012

FOREWORD

This guidance is approved for use by all Departments and Agencies within the Department of Defense (DoD).

The DoD acquires weapons systems, equipment, and platforms that must be sustained as long as thirty years. DoD acquisition and logistics professionals use the term “sustainment” to describe the support required to operate and maintain a system over its lifetime. Globally, the environmental-related term “sustainability” is used to mean a durable and self-sufficient balance between social, economic, and environmental factors. *In the context of the DoD acquisition process, sustainability essentially involves the wise use of resources and the minimization of corresponding impacts and costs during the life cycle.* Resources are costly and, in many cases, dwindling. Systems must be made more sustainable in order to meet mission requirements into the future and reduce life cycle costs. Without a full understanding of life cycle impacts and costs of systems and platforms, significant impacts and costs are often “pushed downstream” from acquisition program managers to the DoD operational, logistics, and installations management communities.

This guidance describes how a sustainability assessment, used in early conceptual and design decisions, can help design more sustainable systems – those which use less resources over the life cycle, have reduced impacts on human health and the environment, and thus have lower life cycle costs. A sustainability assessment allows more robust and informed trade space and supportability analyses. Sustainability assessments include:

(1) A method called Life Cycle Assessment (LCA), which examines the impacts of alternative uses of resources such as energy, water, chemicals and materials, and land. This document provides guidance for conducting a Streamlined Life Cycle Assessment (SLCA), which was developed specifically for DoD’s acquisition process. It also provides a reference to an automated tool for completing the calculations needed to compare alternatives for sustainability. SLCA for sustainability should be integrated into the overall Systems Engineering (SE) process as described in the Defense Acquisition Guidance Chapter 4 on Systems Engineering.

(2) A Life Cycle Cost Analysis (LCCA), which gathers the life cycle costs related to the use of resources and their impacts on human health and the environment. A sustainability assessment can help reduce Total Ownership Costs of systems by uncovering hidden or ignored life cycle costs thereby allowing more informed design decisions early in the process. It will also improve the accuracy of system life cycle cost estimates.

Executive Order (E.O.) 13514 of October 5, 2009 entitled “Federal Leadership in Environmental, Energy and Economic Performance” establishes an integrated strategy for sustainability in the Federal Government. As required by the E.O., DoD developed a Strategic Sustainability Performance Plan (SSPP) that is updated annually. The SSPP includes DoD goals for efficiency and reductions in energy, water, solid waste, and use of hazardous chemicals and materials. Sustainability assessments will help DoD managers make design, logistics, and sustainment decisions that will help achieve these goals.

All comments (recommendations, additions, and deletions) and any pertinent, beneficial document information may be addressed to Office of the Deputy Under Secretary of Defense (Installations & Environment), Environmental Readiness & Safety, 1225 S. Clark Street, Arlington, VA 22202 or e-mailed to paul.yaroschak@osd.mil. Since contact information may change, please verify the currency of this address information using the Acquisition Streamlining and Standardization Information System (ASSIST) online database at http://assist.daps.dla.mil/.

CONTENTS

1. SCOPE

1.1 Scope. The purpose of this document is to introduce the concept of sustainability assessments and provide detailed guidance on how to conduct a Streamlined Life Cycle Assessment (SLCA). Sustainability assessments comprise a method called Life Cycle Assessment (LCA)[1], which assesses human health and environmental impacts, and Life Cycle Costs Analysis (LCCA)[2], which captures related life cycle costs. The guidance provided in this document focuses specifically on a type of LCA known as SLCA, which retains the basic concepts of a traditional ISO 14040 LCA while reducing the time, resources, and data needed to conduct the assessment. This guidance describes how to utilize existing data from legacy systems or proxy data from similar systems to conduct a SLCA.

This document is for guidance only and cannot be cited as a requirement. However, the intent is for this guidance to be incorporated into the U.S. DoD Integrated Defense Acquisition, Technology, and Logistics Life Cycle Management System to inform design, tradeoff and resource allocation decisions. This guidance is applicable to numerous members of the acquisition community including: 1) Program Managers; 2) the Analysis of Alternatives (AoA) study team or other alternative evaluators; 3) the Milestone Decision Authority (MDA); 4) Systems Engineers; 5) Resource Sponsors; and 6) Requirement Sponsors.

This guidance can be applied to new weapon system and platform acquisitions[3] as well as legacy systems[4]. The SLCA method can be used to assess human health and environmental impacts of an entire system, subsystem, component, process or activity. While the SLCA method is applicable to numerous stages in DoD acquisition, it is highly recommended that this guidance be used to inform the following key decisions prior to Milestone B: 1) the AoA tradeoff analysis, or other alternative assessments, and proposed materiel solution; 2) any major prototype decisions made during the Technology Development phase; and 3) the Preliminary Design Review (PDR).

2. APPLICABLE DOCUMENTS

2.1 General. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

2.2 Government Documents.

[1] See ISO (the International Organization for Standardization) 14040 series on life cycle assessment (LCA).

[2] See DoD life cycle cost analysis (LCCA) guidebooks such as DoD Product Support Business Case Analysis (BCA) Guidebook, DoD Product Support Manager Guidebook, and CAPE Operating & Support Cost Estimating Guide.

[3] A new system is considered any system that enters the Integrated Defense Acquisition, Technology, and Logistics Life Cycle Management System prior to Milestone B.

[4] Legacy systems are considered systems already passed Milestone B, but may be undergoing notable modifications or revised operation and maintenance procedures.

2.2.1 Other Government documents, drawings, and publications. The following other Government documents, drawings, and publications form a part of this document to the extent specified herein.

Defense Acquisition Guidebook (available at https://dag.dau.mil/)

Executive Order 13514 Federal Leadership in Environmental, Energy and Economic Performance

Department of Defense Strategic Sustainability Performance Plan (SSPP) (available at http://www.acq.osd.mil/ie/)

Department of Defense Product Support Business Case Analysis (BCA) Guidebook

Department of Defense Product Support Manager Guidebook

CAPE Operating & Support Cost Estimating Guide

Department of Defense Instruction 5000.02 (available at https://dag.dau.mil/)

2.3 Non-Government publications. The following documents form a part of this document to the extent specified herein.

ISO (THE INTERNATIONAL ORGANIZATION FOR STANDARDIZATION)

ISO 14040	Environmental management – Life cycle assessment – Principles and framework
ISO 14044	Environmental management – Life cycle assessment – Requirements and guidelines

3. DEFINITIONS

3.1 Acronyms used in this standard. The acronyms used in this standard are defined as follows:

ACAT	Acquisition Category
AoA	Analysis of Alternatives
CCD	Capability Development Document
CFC	Chlorofluorocarbons
CONOPS	Concept of Operations

dBA	Decibel A-weighting
DoD	U.S. Department of Defense
E.O.	Executive Order
EPA	U.S. Environmental Protection Agency
HCFC	Hydrochlorofluorocarbon
ICD	Initial Capabilities Document
ISO	International Standard Organization
LCA	Life Cycle Assessment
LCCA	Life Cycle Cost Analysis
MDA	Milestone Decision Authority
MDAP	Major Defense Acquisition Program
MT	Mission Task
O&S	Operations and Support
PDR	Preliminary Design Review
SE	Systems Engineering
SLCA	Streamlined Life Cycle Assessment
SME	Subject Matter Expert
SSPP	Strategic Sustainability Performance Plan

3.2 Definitions. Within this document, the following definitions apply:

3.2.1 Activity Descriptor. Key characteristics of a system that describe that system's function or purpose. An activity descriptor is used to identify activities resulting in high life cycle human health and environmental impacts.

3.2.2 Areas of Concern. An area of concern represents a prevention point, an area where potential harm can be minimized and protection of areas worth maintaining can be maximized.

3.2.3 Basing space. Land use that includes, but is not limited to, piers, shoreline, runways, and hangars and should be included in evaluation of alternatives using LCA methods.

3.2.4 Characterization Factor. A conversion factor applied to convert an inventory input to an impact within an area of concern. Characterization factors are derived from risk assessment and scientific literature.

3.2.5 Closed-loop system design. Closed-loop system design reuses resources such that waste generation is reduced or eliminated. Resources requirements such as energy, chemicals and materials, and water are also drastically minimized or eliminated.

3.2.6 Cost-effective. Implies that either:

a. An alternative is less costly than, or cost equivalent to, other assessed alternatives while producing the same or greater amount of benefit throughout the system's life cycle; or

b. The net life cycle benefits (i.e., indirect cost savings, reduced environmental or human health impact, etc.) of an alternative offset any incremental costs incurred above the costs of other compared alternatives.

3.2.7 Direct energy. The amount of energy required to operate a system throughout its life cycle, including energy required by all subsystem components.

3.2.8 Direct Water. The amount of water required to operate a system throughout its life cycle, including water required by all subsystem components.

3.2.9 Emission Factor. An emission factor is the average emission rate of a given pollutant from a given source relative to the intensity of a specific activity; for example grams of carbon dioxide released per megajoule of energy produced.

3.2.10 End-of-life. A life cycle phase included within streamlined life cycle assessment (SLCA). End-of-life management activities include decommissioning, demilitarization, disposal, re-using, re-purposing, recycling, incinerating, and land filling.

3.2.11 Functional unit. The functional unit defines the identified functions (performance characteristics) of a system. The primary purpose of a functional unit is to provide a reference to which the inputs and outputs of a specified system are related. This reference is necessary to ensure comparability of streamlined life cycle assessment (SLCA) results across alternative systems. For a further explanation please see ISO 14040 and 14044.

3.2.12 Hazardous chemical. A chemical that presents a physical or health hazard and for which a facility must maintain a Material Safety Data Sheet or other safety data information.

3.2.13 Incremental land use. An area of undeveloped land that would be developed for the purpose of supporting activities directly or indirectly tied to the newly acquired system (system use, basing, maintenance, system support infrastructure, etc.). The term incremental implies that this land would only be developed as a result of acquiring the new system.

3.2.14 Indirect energy. The amount of energy required to manufacture, sustain (e.g., maintain, transport, decommission, etc.) and protect the system, excluding any energy needed to directly operate the system (direct energy). This includes the total energy needed to protect and supply the alternative.

3.2.15 Indirect water. The amount of water used to manufacture, sustain (e.g., maintain, transport, decommission, etc.) and protect the system, excluding any water needed to directly operate the system (direct water). This includes the total water needed to protect and supply the alternative.

3.2.16 Life cycle assessment (LCA). The compilation and evaluation of the inputs, outputs, and the potential impacts to human health and the environment of a system throughout its life cycle. LCA is a technique used to assess the environmental aspects and potential impacts associated with a product, process, or service, by:

a. Compiling an inventory of relevant energy and material inputs and environmental releases;
b. Evaluating the potential environmental impacts associated with identified inputs and environmental releases;
c. Interpreting the results to inform decision making.

3.2.17 Materiel solution. Correction of a deficiency, satisfaction of a capability gap or incorporation of new technology that results in the development, acquisition, procurement or fielding of a new item (including ships, tanks, self-propelled weapons, aircraft, etc., and related software, spares, repair parts and support equipment, but excluding real property, installations and utilities) necessary to equip, operate, maintain and support military activities without disruption as to its application for administrative or combat purposes. In the case of family of systems and system of systems approaches, an individual materiel solution may not fully satisfy a necessary capability gap on its own.

3.2.18 Mission Critical. A system that performs an intended function, the loss of which would cause the stoppage or failure of warfighter operations or direct mission support of warfighter operations.

3.2.19 Mission task (MT). Derived directly from the capability requirements identified in the ICD or CDD. MTs are usually expressed in terms of general tasks to be performed or effects to be achieved, in this case, sustainability.

3.2.20 Non-Renewable Energy. Energy from a source that cannot be replenished naturally within human timescales.

3.2.21 Operations and Sustainment (O&S). A life cycle phase in the Integrated Defense Acquisition, Technology, and Logistics Life Cycle Management System that falls within the SLCA study boundaries discussed in this guidance.

3.2.22 Operational space. Land use that includes, but is not limited to, areas where military operations are conducted (e.g., theater). This type of land should not be included in the evaluation of alternatives using LCA methods for assessing impact to land.

3.2.23 Ordinal ranking. Rank ordering, but not relative to magnitude (i.e., size or degree) of difference between items being measured. Rank ordered data is assigned a place such as 1st, 2nd, 3rd, etc.

3.2.24 Production and deployment. A life cycle phase in the Integrated Defense Acquisition, Technology, and Logistics Life Cycle Management System that falls within the SLCA study boundaries discussed in this guidance.

3.2.25 Raw material acquisition. A life cycle phase typically included within LCA. Raw material acquisition includes harvesting and processing natural resources from the environment.

3.2.26 Recycle. A substance is considered recyclable if it is captured as waste and reprocessed to create a new product for a new application.

3.2.27 Renewable energy. Energy from a source that can be replenished naturally within a short period of time. Renewable energy comes from renewable sources that are captured from on-going natural processes, including, but not limited to: sunlight, wind, tidal dynamics, photosynthesis, and geothermal heat flows.

3.2.28 Restoration time. The duration, typically in years, required for a transformed plot of land to be naturally restored to its pre-transformed state.

3.2.29 Reuse. A chemical, material, or object that is used for another application, usually after refurbishing, once the lifespan of the original application is exhausted.

3.2.30 Scoring Factor. An indexed unit that allows the evaluator to quickly estimate the level of impact for a given impact category by multiplying that factor by the quantity of a specified input. A scoring factor combines the aggregation of all relevant emission factors needed to estimate outputs from a specified input and the characterization factor needed to convert that output to appropriate impact units.

3.2.31 Sustainable acquisition. Acquisition conducted in a manner that results in a system design that minimizes impacts on mission, human health, and the environment while meeting performance parameters.

3.2.32 Sustainability. Sustainability means a durable and self-sufficient balance between social, economic, and environmental factors. In the context of the DoD acquisition process, sustainability essentially involves the wise use of resources and the minimization of corresponding impacts and costs during the life cycle.

3.2.34 Sustainability assessment. Within the context of this document, a "sustainability assessment" comprises both a Life Cycle Assessment, which evaluates human health and environmental impacts, as well as a Life Cycle Cost Analysis (LCCA), which captures life cycle costs of system, product, or process.

3.2.35 Sustainable design. Implementation of sustainable elements in new product systems. These elements may include the use of low-impact materials, optimization of system-wide energy and water consumption, minimization of waste products through closed-loop design, and reduction of pollution emissions throughout the life cycle of the system.

3.2.36 Streamlined LCA (SLCA). An approach to LCA accomplished by limiting the scope of the study or simplifying the modeling procedures, thereby limiting the amount of data or information needed for the assessment.

3.2.46 System boundary. A set of criteria specifying which activities are included as part of an acquired system's life cycle. The system boundaries comprise the unit processes or activities that will be included within a sustainability assessment and should be consistent with the stated goal of the assessment.

3.2.47 Water degradation. When the water discharged (or treated and then discharged) after the completion of a specified activity is of lower quality than the quality of the original source. This definition should not be confused with the legal definition of "degradation" under the Clean Water Act.

4. SUSTAINABILITY IN DOD ACQUISITION

The DoD is undergoing numerous efforts to improve overall sustainability[5] throughout its operations. Due to sustainment requirements, weapons systems and platforms use significant quantities of resources over their life cycle and thus have significant impacts on sustainability. The goal of this guidance is to help program managers acquire the most sustainable systems capable of meeting performance requirements as outlined in the Initial Capabilities Document (ICD) or the Capability Development Document (CCD).

4.1 Sustainability Assessments. Within the context of this document, a "sustainability assessment" comprises both a Life Cycle Assessment, which evaluates human health and environmental impacts, as well as a Life Cycle Cost Analysis (LCCA), which captures life cycle costs of system, product, or process (Figure 1). A sustainability assessment involves a qualitative and quantitative comparison of the key impacts that a product, system, service, or activity will have on human health, the environment and the mission throughout its life cycle.

[5] "The Department's vision of sustainability is to maintain the ability to operate into the future without decline – either in the mission or in the natural and manufactured systems that support it. DoD embraces sustainability as a means of improving mission accomplishment." Definition is from the DoD's SSPP 2010.

Sustainability assessments provide an integrated management approach to measure and minimize the impacts of a product, system, or activity from cradle (e.g., raw material acquisition) to grave (e.g., end-of-life).

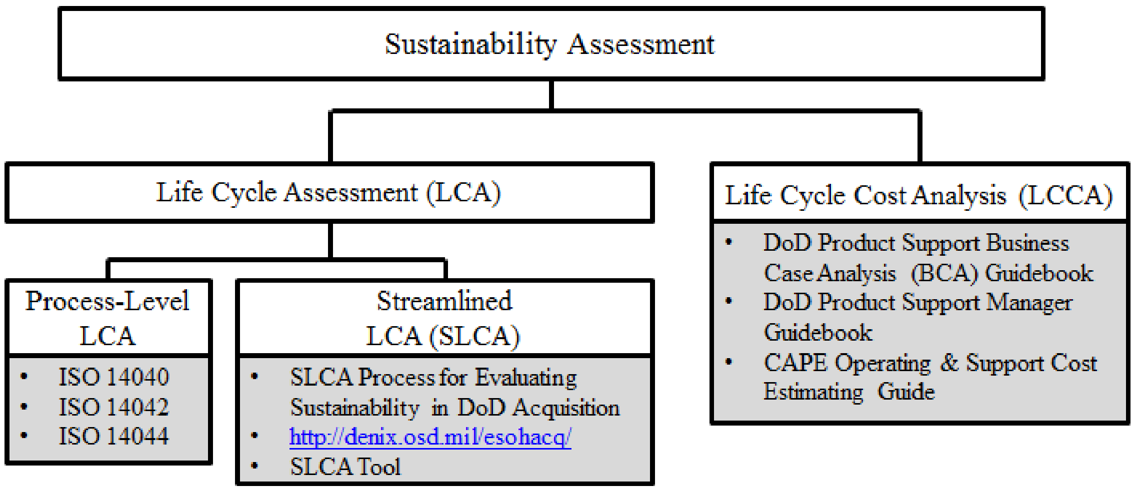

FIGURE 1. Diagram of a sustainability assessment including guidance documents for process-level LCA, streamlined LCA (SLCA), and life cycle cost analysis (LCCA)

Sustainability assessments employ a systems-based approach, meaning that the mission, human health and environmental impacts, as well as life cycle costs, of each component comprising a greater system are evaluated. A sustainability assessment should capture the interrelated nature of impacts resulting from design choices. For example, a design choice to use less energy may come at the expense of increasing water use, which in turn may reduce the impact to global warming but increase the impact to water scarcity. A sustainability assessment should capture these tradeoffs as well as capture the associated life cycle costs of various design choices. The SLCA method described in this document provides guidance on how to assess the complex web of relationships among mission, human health and environmental impacts to better inform system or component design and justify tradeoffs.

4.2 The importance of Sustainability Assessments to DoD. System design is the most crucial step towards ensuring sustainable acquisitions. Early materiel and design decisions establish the foundation for cost, technological capability, resource consumption, and potential impacts to mission, human health and the environment. A sustainability assessment facilitates sustainable acquisitions by requiring data, information, and knowledge about a system and its life cycle early in the design process. Incorporating sustainability assessments into the acquisition process requires optimizing the trade space among performance, schedule, life cycle cost, and sustainability. Conducting sustainability assessments will enable the acquisition community to comply with DoD's cost-control requirements and sustainability goals.

4.2.1 Principles of Sustainable Design. The following is a list of general principles that guide sustainable design. Sustainability assessments encourage these design principles, which will support the DoD in efforts to reduce life cycle costs and minimize human health and environmental impacts. Whenever technologically feasible and cost-effective, newly acquired systems should:

a. Utilize low-impact materials that are: (1) non-toxic, as designated by the U.S. Environmental Protection Agency (EPA); (2) from life cycle-enhancing renewable sources; (3) from local or regional sources (with regard to where the system is manufactured or assembled); and (4) composed of recycled materials that require less energy to process than non-recycled substitute materials.
b. Optimize system-wide energy consumption by: (1) reducing the fully burdened cost of delivered energy, in accordance with Enclosure 7 of DoD Instruction 5000.02; (2) designing manufacturing and assembly processes that minimize energy consumption; (3) developing systems that employ energy efficiency technologies during the use phase of the life cycle; (4) developing end-of-life scenarios for which systems can be easily disposed, recycled or reused with minimal energy input; and (5) utilizing life cycle-enhancing renewable sources of energy.
c. Improve system and component design by: (1) extending the expected life of components and minimizing maintenance activities and materials by improving durability; (2) standardizing component function for reuse in newer versions of that same system or for reuse in other similar systems; and (3) minimizing the use of designs that far exceed specifications when such designs require additional materials and energy and result in excess waste and pollution and when less impactful alternative designs adequately achieve all specifications.
d. Minimize life cycle waste by: (1) reusing waste materials from manufacturing, use and end-of-life activities; (2) reusing system components with a longer lifetime than the systems they comprise and recycling materials to create new system components; (3) increasing the life of a system through rigorous maintenance and repair schedules; (4) developing waste-to-fuel capabilities; and (5) integrating closed-loop system design.
e. Minimize life cycle pollution by: (1) reducing the use of hazardous materials and fossil fuel energy sources that lead to pollution emissions; (2) engaging in pretreatment activities that mitigate pollution emissions; and (3) collecting and treating pollution emissions before they enter the surrounding community or ecosystem.
f. Minimize risks by: (1) designing out known chemical, biological and physical hazards (including noise, radiation, and ergonomic stressors) when technologically feasible; (2) ensuring that workplace and environmental exposures to known hazards are inherently safe or below recognized limits.

4.3 Sustainability Assessments in Acquisition Phases. Sustainability assessments, as discussed in Defense Acquisition Guide, Section 4.3, are an integral part of the systems engineering design process. Regardless of the life cycle phase, incorporating sustainability into acquisition begins with requirements to minimize resource use and impacts to human health and the environment, as well as related life cycle costs in system design. These requirements inform the design and development of reliable, maintainable, and affordable systems through the continuous application of the systems engineering methodology.

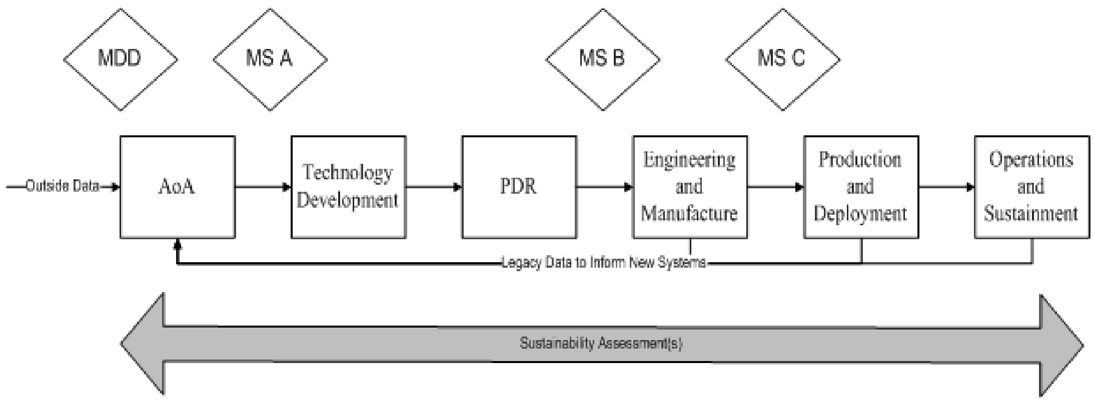

FIGURE 2. Sustainability assessment(s) in acquisition phases

As part of a system's life cycle management, a sustainability assessment should be completed in three phases relative to the phases set forth in the Defense Acquisition, Technology, and Logistics Life Cycle Management System. These three broad phases are (1) Pre-Systems Acquisition (pre-Milestone A); (2) Acquisition; and (3) Operations. To have the greatest influence on system design, sustainability assessments should, at the very least, occur during the Material Solution Analysis Phase (pre-Milestone A) and Technology Development Phase (pre-Milestone B). It is also recommended that sustainability assessments continue after Milestone B, including sustainment and end-of-life activities (Figure 2). It is important to note that sustainability remains a factor throughout acquisition and should still be evaluated even if the system's entry into the acquisition phase is later, as directed by Materiel Development Decision (MDD) and authorized by the Milestone Decision Authority (MDA).

4.3.1 Pre-Systems Acquisition (pre-Milestone A). Pre-Milestone A establishes the capabilities and major constraints (e.g., cost, schedule, available technology, etc.), which frame the acquisition strategy and program structure for both the system and its support. This period includes the Materiel Solution Analysis Phase. Sustainability assessments conducted pre-Milestone A evaluate the resources required by each materiel solution. The resources required by each materiel solution throughout its life cycle determine human health and environmental impacts in addition to life cycle costs. Generally, the sustainability assessment should start at the system level but can selectively go to lower levels of indenture (e.g., components) if key enabling technologies are required to meet the concept of operations (CONOPS)—for both the system and the product support system.

The Analysis of Alternatives (AoA)[6] is the primary document pre-Milestone A, which should include results from sustainability assessments. Sustainability assessments inform both components of the AoA, the Effectiveness Analysis and the Cost Analysis. The initial scoping of the sustainability assessment begins with the AoA Study Guidance. The AoA Study

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[6] The results of the sustainability assessment shall be reported in all formally commissioned AoAs. DoDI 5000.02 identifies the statutory requirements for AoAs and the AoA procedural responsibilities; the process is further detailed in the Defense Acquisition Guidebook.

Guidance, in addition to the AoA, should be informed by a sustainability assessment and updated accordingly as both documents evolve during the acquisition process.

4.3.2 Acquisition. The Acquisition Period consists of designing, producing, and deploying the equipment and its support system. This period includes the Technology Development (pre-Milestone B), Engineering and Manufacturing Development (pre-Milestone C), and the Production and Deployment (post-Milestone C) Phases. During the Acquisition Period, sustainability assessments should be used to inform the design process by assessing the impact that system plans, development and production have on sustainability, in conjunction with the system's effectiveness, readiness, and affordability—which is captured by a complete analysis of the system's life cycle costs. The intent is to act early to mitigate circumstances that may adversely impact deployed readiness, which includes:

a. Using the systems engineering process to design a more sustainable system and supply requirements; and
b. Testing to verify that the total system requirements have been achieved and in a manner that minimizes life cycle costs, resource consumption, and human health and environmental impacts.

During this period, more realistic and detailed data are used in the models and simulations to reduce risk. The resource requirements, which drive costs as well as human health and environmental impacts, are further refined.

The Preliminary Design Document (PDR) is the primary document during the Acquisition Phase, which should include results from sustainability assessments. The PDR should demonstrate how principles of sustainable design (see 4.2.1) were incorporated into the system in preparation for Milestone B approval. The Analysis of Alternatives (updated as necessary after Milestone A) should document the chosen system's refined sustainability assessment.

4.3.3 Operations & Sustainment (O&S). The O&S Period consists of adjusting to the operational environment by assessing readiness trends and issues, cost trends, evolving materiel conditions, and taking timely corrective actions to support the users. Sustainability assessments should inform the Life Cycle Sustainment Plan. Specifically, the sustainability assessment should inform the level of a program's achieved effectiveness by:

1. Analyzing the impact of proposed redesign alternatives on resource consumption, human health, the environment, life cycle costs, and mission effectiveness.

2. Utilizing operation data, including Failure & Discrepancy Reports, to:

    a. Project trends (with confidence levels) to encourage the use of proactive actions to minimize adverse impacts on the users;

    b. Identify areas in the supply chain where performance is adversely affecting materiel availability, increasing ownership costs or missing areas of potential savings or improvements (Note, that in some cases, an increase within a specific system may be significantly offset by a major saving elsewhere within the DoD Component or DoD. Consequently, it may be beneficial to involve higher level organizations in these decisions.); and

c. Identify and analyze readiness risk areas and develop corrective action alternatives. An example is the risk of chemical or material availability due to human health or environmental regulations.

3. Relate or quantify various business process outcomes with required resources and corresponding impacts.

4.4 Factors that influence a Sustainability Assessment. The amount of information needed to conduct a sustainability assessment depends on a number of factors, including the:

a. Acquisition Category (ACAT);
b. Acquisition milestone, phase, or decision point;
c. Maturity of the alternatives and available data;
d. The acquisition strategy (evolutionary or single step to full capability); and
e. As directed (i.e., tailored), by the Program Manager (PM) and the MDA (and their designees), if applicable.

For example, sustainability assessments for Major Defense Acquisition Program (MDAP) ACAT I acquisitions may be expansive and technically rigorous while some small ACAT III acquisitions may have smaller and narrowly focused sustainability assessments. Similarly, a sustainability assessment might be predominantly qualitative early in the materiel development process due to a general lack of data. Regardless of the ACAT designation, when acquisitions involve legacy platforms, past data from those systems should be used to support the sustainability assessment. In some cases, a sustainability assessment may only identify what is unknown about the system in terms of resource requirements, human health and environmental impacts, and life cycle costs.

5. OVERVIEW OF THE STREAMLINED LIFE CYCLE ASSESSMENT (SLCA)

In this guidance, streamlined life cycle assessment (SLCA) is introduced as the recommended approach for assessing resource consumption and impacts to human health and the environment. The SLCA is derived from the standardized method for conducting LCA as documented in the ISO 14040 series: goal and scope definition, inventory analysis, impact assessment, and interpretation. However, the SLCA is a simplified and less robust version of LCA; it prescribes and limits the scope, data requirements, and range of impacts assessed.

SLCA comprises a series of steps intended to inventory resource requirements and model human health and environmental impacts associated with a system. It evaluates the energy, water, land, and chemical and material inputs to the system and the associated emissions and waste outputs from the system across its life cycle to assess the potential impacts to human health, environmental health, and mission. The life cycle of a system includes four general phases: (1) raw material acquisition; (2) production and deployment; (3) operation and sustainment (O&S); and (4) end of life.

The purpose of the SLCA is to compare two or more systems, sub-systems, or components with the same function (e.g., alternate product systems with similar expectations of performance) on the basis of potential for human health and environmental impacts. Further discussion of the functional unit can be found in 6.1. The results of the SLCA are then used to compare the relative magnitude of impacts between or among alternate systems for a given impact category. Results are amenable to visual presentation using spider web diagrams that illustrate relative values and the magnitude of the values. The results inform product or process design analyses and provide decision support for decision makers who must meet sustainability goals.

The SLCA framework (Figure 3) is structured to clearly identify all inputs (e.g., energy, chemicals and materials, water, and land) entering the system and the areas of concern to which the inputs are assigned.

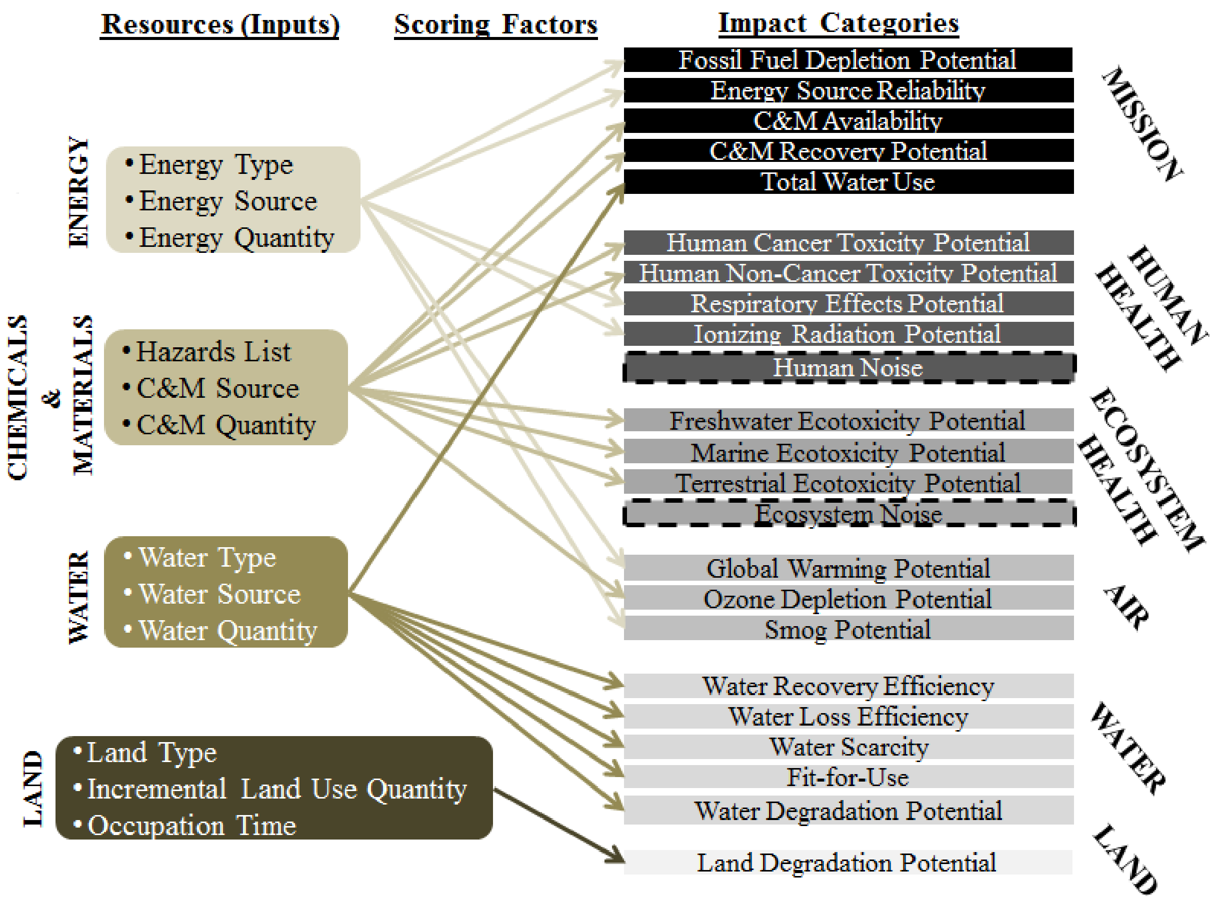

FIGURE 3. Streamlined Life Cycle Assessment (SLCA) Framework

The SLCA evaluates the energy, water, land, and chemicals and materials needed by the system across its life cycle. The inventory of these inputs includes the type, source, and quantities used by the system and used to support and maintain the system. Inputs are not mutually exclusive to impact categories. For example, energy use results in impacts across multiple categories to mission, air, and human health.

This SLCA differs from the traditional process-level LCA, as document by ISO 14040 series, in that it does not require evaluators to specify activities or processes that occur within the study boundaries (see 6.3) and estimate resulting system emissions from those specified activities or processes. Instead the SLCA utilizes scoring factors to classify the inventory of inputs into impact categories and to determine the magnitude of impact. The scoring factors are based on: (1) generalized emission factors related to associated inputs[7] and (2) characterization factors derived from risk assessment and LCA scientific literature (Appendix D). In doing so, evaluators are only required to develop an inventory of inputs into the system, for which generalized resulting impacts are assumed. Because the scoring factors are generalized, the calculated impacts should not be considered as robust as those calculated using traditional process-level LCA described in ISO 14040 series. Figure 4 provides a visual explanation for how this SLCA differs from traditional process-level LCA.

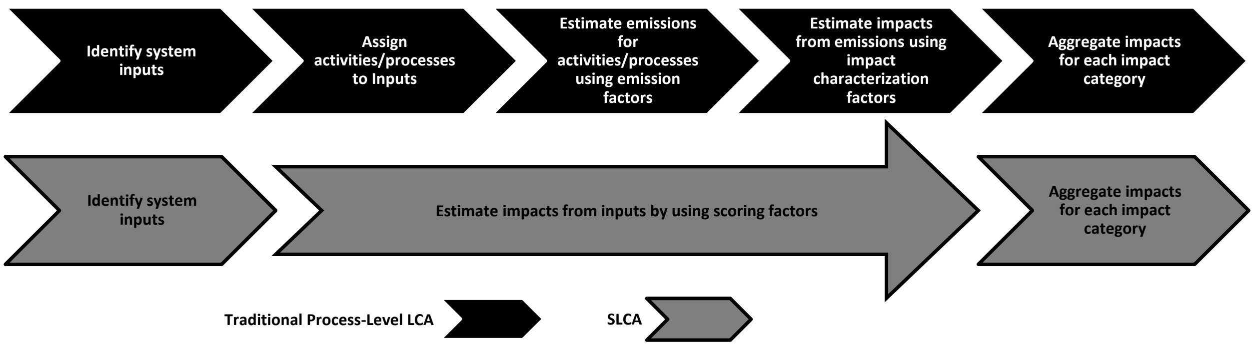

FIGURE 4. Comparing SLCA with traditional process-level LCA

The SLCA classifies the inventory of inputs into impact categories representing six environmental areas of concern. Areas of concern are mission, air, water, land human health, and ecosystem health. An area of concern represents a prevention point, an area where potential harm can be minimized and protection of areas worth maintaining can be maximized. The six areas of concern comprise 23 impact categories as shown in Figure 3.

6. CONDUCTING THE SLCA

There are six high-level steps to conducting a SLCA:

STEP 1: Defining the Functional Unit (Section 6.1)
STEP 2: Defining the Scope (Section 6.2)
STEP 3: Defining the System Boundaries (Section 6.3)
STEP 4: Building an Input Inventory (Section 6.4)
STEP 5: Assessing Mission, Human Health, and Environmental Impacts (Section 6.5)

[7] For further explanation on emission factors, see Notes & Sources in the SLCA tool available at http://denix.osd.mil/esohacq/.

STEP 6: Comparing Alternatives (Section 6.6)

The following sections provide guidance on how to complete each of the six steps for conducting a SLCA.

6.1 Defining the Functional Unit. The functional unit defines the identified functions (performance characteristics) of a system. The primary purpose of a functional unit is to provide a reference to which the resource requirements and resulting impacts of a specified system are related. This reference is necessary to ensure comparability of results across alternative systems. Comparability of results is particularly critical when different systems are being assessed, to ensure that such comparisons are made on a common basis. Thus, a functional unit is a common unit of measure that: 1) provides a reference for the system inputs and outputs; 2) assures equivalence; 3) allows for meaningful comparisons between alternative systems; and 4) identifies elements that all of the alternatives under study have in common.

The functional unit for a system or component should be defined by the minimal requirements determined necessary to properly meet the stated capability, as outlined in Integrated Capabilities Document (ICD), the Capability Development Document (CDD), or a specific component performance requirement. It is critical that the functional unit be the same for all systems or components being assessed.

NOTE: Both time and number of mission tasks needed to fulfill a desired capability are elements of the functional unit. Examples that demonstrate the importance for including time and number of mission tasks are provided below:

a. Time Example: The functional unit is to meet a capability over a 50-year period. Alternative X is expected to have a lifespan of 25 years, while Alternative Y has a life span of 50 years. Thus, two units of Alternative X are needed to meet the minimal capability requirements, while only one unit of Alternative Y is needed. In this example, one unit of Alternative Y may have greater impacts (which include human health and environmental impacts) over its life cycle compared to one unit of Alternative X. However, when considering that two units of Alternative X are needed to meet the functional unit, the cumulative impacts of selecting Alternative X are greater than the impacts of Alternative Y.

b. Mission Task Example: The number of mission tasks needed to meet the minimum capability also should be considered. For example, the defined functional unit is to transport 100 combat vehicles 200 miles. In this example, Alternative X has half the transport capacity of Alternative Y. Thus, Alternative X has to take twice the number of trips as Alternative Y in order to fulfill the functional unit. Alternative Y may be less fuel efficient than Alternative X. However, since Alternative X has to take twice the number of trips as Alternative Y, the impacts of the two materiel solutions may favor Alternative Y over Alternative X.

6.2 Defining the Scope. The scope defines the system, subsystems, support systems, and components to be included in the SLCA analysis. The system scope for each alternative should include all incremental materiel (e.g., systems, components, subcomponents) needed to be acquired to fulfill the capability gap specified by the ICD or CDD, or performance criteria, as standardized across all alternatives by the functional unit.

The system scope should also include all incremental support and sustainment systems required to fulfill the desired capability. For example, suppose that the stated capability, as described by the functional unit, can be met using a missile, but the newly acquired missile cannot be deployed using existing platforms. This situation would require a systems-of-systems acquisition, for which a new launching platform, in addition to the newly acquired missile, must also be acquired. Extending the system's (i.e., the missile) scope to also include the launching platform ensures that all incremental impacts (e.g., incremental land use) resulting from the acquisition are accounted for in the SLCA. It is important that the defined scope be the same for all alternatives being assessed. Since the SLCA is a relative assessment, inconsistency in how the scope is defined can introduce error and unintended bias into the analysis.

6.3 Defining the Study Boundaries. Defining the boundaries of a SLCA determines the system life cycle phases included in the assessment. A clear definition of the study boundaries enables a better assessment for each alternative's direct and indirect impacts, while also ensuring an equitable comparison amongst all alternatives.

A simplistic, high-level mapping of the system acquisition process is illustrated in Figure 5. Figure 5 also shows the life cycle phases to be included in a SLCA, which are Raw Materials Acquisition, Production/Deployment, O&S, and End of Life. It is important to note that these general boundaries may not apply to all SLCAs and can be adjusted on a case-by-case basis.

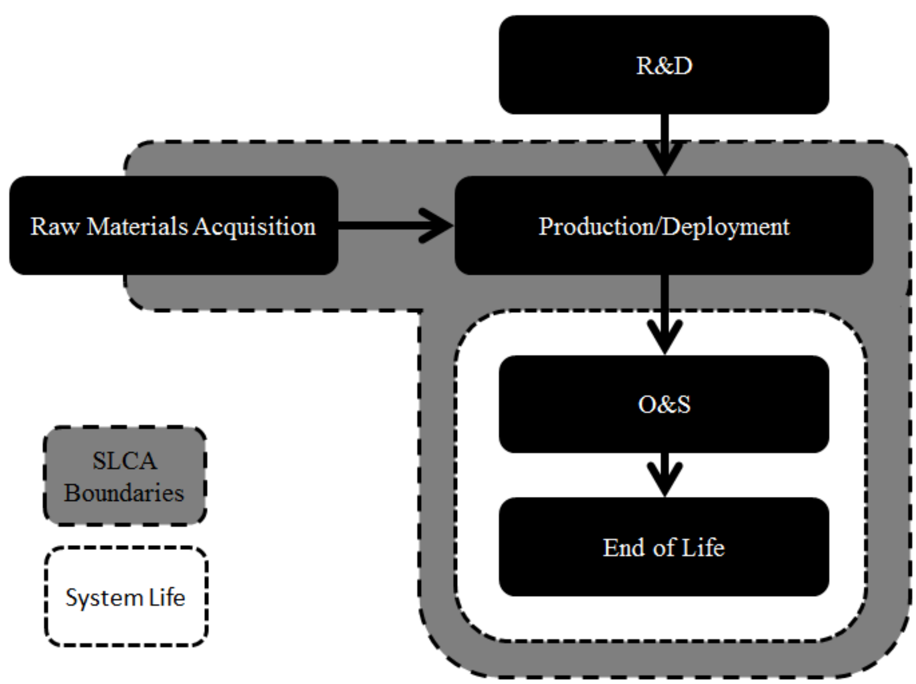

FIGURE 5. SLCA study boundaries

When conducting a SLCA, it is important to include processes, products, infrastructure and activities within the study boundaries as determined appropriate by:

a. The scale of the weapon system being evaluated;
b. The availability of data; and
c. The objectives of the evaluation.

In instances when the DoD has direct influence over the procurement of some or all of the raw materials comprising the materiel solution, and adequate data exists for use in a SLCA, raw materials acquisition should be included in the study boundaries. In cases where DoD does not control or influence how and where raw materials for the system are acquired, the raw materials acquisition phase may be excluded.

Best practice dictates that a justification is provided if the following are excluded from SLCA study boundaries: 1) key processes, products, infrastructure and activities that significantly influence the assessment; or 2) the life cycle phases recommended in this section. When comparing materiel alternatives, the boundaries and the life cycle phases included in the assessment shall remain the same for all evaluated alternatives to ensure a comparative assessment.

6.4 <u>Building an Input Inventory.</u> Building the input inventory for a SLCA requires collecting data on the resources that a system will use throughout its life cycle. The resources are grouped into four general categories:

a. Energy;
b. Chemicals and Materials;
c. Water; and
d. Land.

The following sections provide guidance on how to collect data on a system's life cycle resource requirements—energy, chemicals and materials, water, and land. In addition, descriptions of how energy, chemicals and materials, water, and land relate to sustainable acquisition are provided below.

6.4.1 <u>Energy.</u> When technically feasible and cost-effective, new system acquisitions should:

a. Utilize energy as efficiently as possible;
b. Consume energy in a manner that minimizes harmful environmental impacts (e.g. greenhouse gas emissions, emissions of criteria air pollutants, land change impacts associated with mining, etc.); and
c. Harness energy from feedstocks that are: 1) not cost prohibitive; 2) from life-cycle-enhancing renewable sources; and 3) acquired from readily available sources, either from domestic supplies or from suppliers that are both politically stable and friendly to U.S. trade.

When collecting data on system energy use, evaluators should consider all life cycle energy, both direct and indirect, that is consumed by the system or component. Direct energy is energy consumed directly by the system. For example, the diesel to fuel a ground vehicle is direct energy. Indirect energy is not consumed directly by the system, but is necessary to manufacture, sustain (e.g., maintain, transport, decommission, etc.) and protect the system. Assessing system energy consumption requires calculating the total amount of direct and indirect energy needed to meet the minimum required mission capability (i.e., functional unit, see 6.1), as described in the ICD or CDD.

There are numerous types of energy that a system may consume to fulfill its performance requirements. Appendix C lists the types of energy that should be considered when conducting a SLCA. Evaluators should identify all the different types of energy that a system will consume directly or indirectly throughout its life cycle. After identifying the types of energy consumed by a system, evaluators need to assign quantities to each type of energy that is consumed. Guidance is provided in 6.4.6 on collecting quantity data as well as how to assess quantity when data are unavailable.

As determined by the evaluators, units for energy consumption can be either direct measures of energy, such as kilowatt-hours (kWh), joules (J) and British Thermal Units (BTUs), or measures of energy carriers, such as cubic feet (ft^3) of natural gas and gallons (g) of fuel. If using the SLCA tool developed for defense acquisition (see 6.5.1), energy input data should be recorded in units specified in Appendix C.

6.4.2 <u>Chemicals and Materials.</u> When consistent with the mission and cost-effective, new system acquisitions should aim to eliminate hazardous chemicals and materials during early phases of acquisition to prevent impacts and associated costs, especially during sustainment and disposal phases. Sustainable chemical and material choices ensure availability in terms of economic viability, supply, and natural abundance. Sound chemical and material management promotes: 1) eliminating or reducing chemicals and materials needed throughout the life cycle of a system or component; 2) using non-toxic or less-toxic chemicals and materials; and 3) reusing or recycling chemicals and materials rather than adding them to the waste stream.

To the extent possible, evaluators should identify the chemicals and materials that a system uses throughout its life cycle. A list of chemicals and materials is provided in Appendix C. After identifying the chemicals and materials that a system uses throughout its life cycle, evaluators need to assign quantities to each chemical and material. Guidance is provided in 6.4.6 on collecting quantity data as well as how to assess quantity when data are unavailable. For chemicals and materials data will typically be in mass based units. If using the SLCA tool developed for defense acquisition (see 6.5.1), chemical and material input data should be recorded in units specified in Appendix C.

NOTE: There are hundreds, if not thousands, of chemicals and materials that a system may use throughout its life cycle. Evaluators should use expert judgment on chemicals and materials that need to be included in the SLCA. A chemical or material should be included in the SLCA if it is: 1) toxic or harmful; 2) rare, difficult to acquire, or expensive; 3) or critical to the system.

Additionally, evaluators should be mindful of all chemicals and materials that are used to manufacture the system or are used to support and sustain the system.

6.4.3 <u>Water.</u> When technically feasible and cost-effective, new system acquisitions should use and manage water as efficiently as possible to:

a. Meet basic human needs for water;
b. Maintain long-term renewability;
c. Maintain the existing steady state and quality of ecosystems;
d. Promote efficient use of resources;
e. Encourage water conservation;
f. Encourage water reclamation and reuse;
g. Match source water quality with the water quality needed for use; and
h. Design for resilience and adaptability.

When collecting data on water use, evaluators should consider all direct and indirect uses of water during a system's life cycle. Direct water is water required to operate the system, including all subsystem components. In contrast, indirect water is water required to manufacture, sustain (e.g., maintain, transport, decommission, etc.) and protect the system.

The purpose of assessing water use is to promote systems that use water efficiently. Water can be: 1) withdrawn from multiple sources; 2) reused or replenished to the environment; and 3) lost through processes such as evapotranspiration and human consumption. Figure 6 illustrates the different ways a system may use water including sources for withdrawing water (A, B, and C) and mechanisms for discharging water (C, E, D, and F).

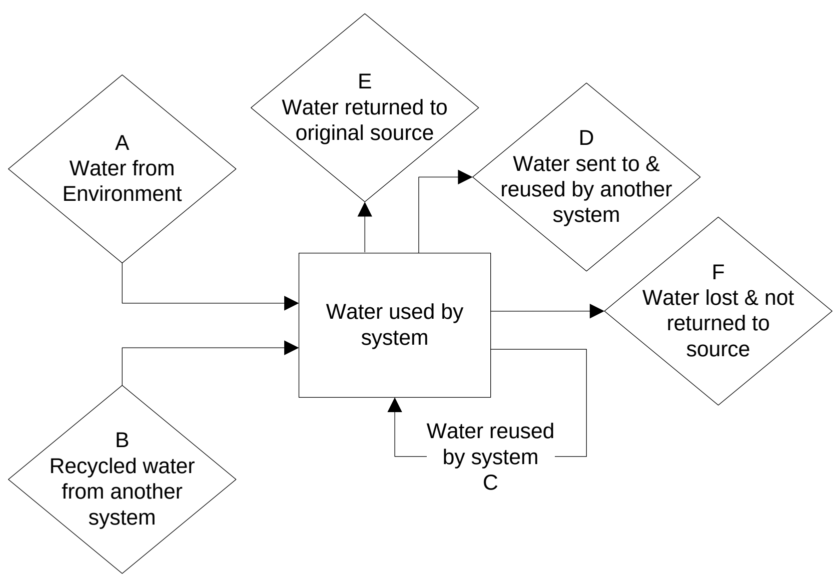

FIGURE 6. Flow diagram for system water use

In order to assess water use efficiency, evaluators need to collect data on:

a. The quantity of water withdrawn from each applicable source (A, B, and C);

b. The quantity of water reused (C and D) or replenished to the environment (E); and
c. The quantity of water lost and not returned to the source (F).

The quantities described above need to be assessed for each activity or process that uses water, either directly or indirectly, throughout a system's life cycle. Guidance is provided in 6.4.6 on collecting quantitative data as well as how to assess quantity when quantitative data are unavailable. For water use, data will typically be in volume-based units. If using the SLCA tool developed for defense acquisition (see 6.5.1), water input data should be recorded in gallons.

6.4.4 Land. Evaluators should consider the amount of incremental land that a system requires throughout its life cycle. For the SLCA, a system's incremental land use should only refer to basing "space", which includes, but is not limited to, land acreage, piers and shoreline, runways, hangers, etc. Operational "space" is not considered in this assessment.

To collect data on land use, evaluators should first identify the incremental amount of physical land that is consumed and transformed to support activities associated with testing, evaluation, basing, and sustaining the system or component. The amount of incremental land should be recorded in acres.

After identifying the incremental amount of land, evaluators should then assign a land type to the area that is being consumed or transformed. Table 1 provides seven categories of land types that evaluators can use to categorize each plot of incremental land used by the system. These categories are organized into how intensely human activities are integrated into the existing landscape; with high intensity indicating high levels of human integration and low intensity indicating low levels of human integration.

TABLE 1. Land categories

Land Type	Abbreviation	Description
Agriculture - High Intensity	Agri_hi	conventional arable, integrated arable, organic arable, fibre/energy crops, intensive meadow
Agriculture - High Intensity	Agri_li	less intensive meadow, organic meadow, organic orchard, natural grassland
Artificially Built Environment -High Intensity	Artificial_hi	built up land, continuous urban, discontinuous urban, sport facilities, industrial area – part with vegetation
Artificially Built Environment -Low Intensity	Artificial_li	green urban, rural settlement, rail embankments
Forest - High Intensity	Forest_hi	forest plantations
Forest - Low Intensity	Forest_li	semi-natural broad-leafed forest (either moist or arid)
Non-use	Non-use	heathland, hedgerows, peatbog

6.4.5 Activity Profile. As part of building an input inventory, evaluators should complete a life cycle Activity Profile for each alternative being considered to identify all major resource requirements and processes within study boundaries that are expected to drive high impact. The purpose of an Activity Profile is to efficiently inform a SLCA, while at the same time reducing the evaluator's data collection burden, by focusing the assessment on activities that have the largest contribution to life cycle impacts. For each alternative, the Activity Profile guides evaluators in targeting key system characteristics and resulting activities, at each life cycle phase, that lead to the greatest impact. This high-level screening process allows evaluators to identify the most important data elements so that limited data-collection resources will capture the highest proportion of total system impact. Once completed, this additional step should significantly reduce the amount of time and resources spent on collecting data for the sustainability assessment.

Although not relevant for the SLCA, it is important to note that the results of an Activity Profile can enhance a LCCA by informing the identification of typically hidden costs (e.g., indirect costs, costs associated with future or contingent liabilities, and external costs) that result from impacts that occur during the production and deployment, operations and sustainment, and end-of-life phases.

Relevant to completing a SLCA, an Activity Profile is specifically used to:

a. Identify the activity descriptors for a system or component (activity descriptor classification);

b. Identify the set of activities that commonly occur within the system or component's activity descriptor classification;

c. Identify activities that have dominant contributions to impacts, as bounded by the assessment boundaries established under 6.3; and

d. Identify the system or component life cycle phases for which these dominant activities occur.

Identifying these important system or component activity descriptors provides vital insight as to which activities drive resource requirements and in which life cycle phases those activities occur. Table 2 provides examples of systems for each combination of these activity descriptors (active and stationary, active and mobile, passive and stationary, and passive and mobile). A detailed explanation of how these combinations of activity descriptors typically influence the assessment regarding each of the sustainability attributes can be found in Appendix A**.**

TABLE 2. Example System/Components Organized by Energy Activity Descriptors

	Stationary	**Mobile**
Active	(a) HVAC System, Water purification System, etc.	(b) Aircraft, Ground Vehicle, Ship, etc.
Passive	(c) Satellite Dish, Barricade Infrastructure, etc.	(d) Trailer, Satellite, Bomb, etc.

a. Active and Stationary Systems. An active and stationary system or component is one that does not move on its own accord and actively consumes resources during its operation to properly achieve its function.

b. Active and Mobile. An active and mobile system or component is one that can move on its own accord and actively consumes resources during its operation to properly achieve its function.

c. Passive and Stationary. A passive and stationary system or component is one that does not move on its own accord and does not consume resources during its operation. Being stationary, these systems and components do not utilize support systems for mobility to properly achieve their function.

d. Passive and Mobile. A passive and mobile system or component is one that is mobilized using support systems (i.e., does not move on its own accord) and does not consume resources during its operation to properly achieve its function.

By defining these key activity descriptors for each alternative, evaluators can better identify the activities and life cycle phases that consume the most resources—energy, chemicals and materials, water, and land. Once doing so, evaluators can enter those activities into a Life Cycle Activity Profile. Table 3 provides a template for completing this profile. When using this template, evaluators should record the high-impact activities that occur in each cell, which represents the impact to a specific attribute during a particular life cycle phase (see example in Appendix B). Once completed, an Activity Profile guides SLCA data collection by identify (1) the resources a system is using and (2) the life cycle phases during which those resources are being consumed. This helps evaluators direct and focuses data collection gathering efforts.

TABLE 3. Example life cycle activity profile template

Attribute	**Life Cycle Phases**			
	Raw Materials Acquisition	***Production & Deployment***	***Operations & Sustainment (O&S)***	***End of life***
Energy				
Water				
Chemicals & Materials				
Land Use				
Hazards				

6.4.6 Collecting data for the SLCA. Before collecting data for the SLCA methodology, it is helpful for evaluators to first: 1) record what data exist and are available for the assessment; 2) identify where that data is housed and who owns it; and 3) identify the format of that data.

Whenever possible, evaluators should use verifiable data to conduct a SLCA. In many cases, however, data needed to conduct the SLCA will not exist. As a result, evaluators will have to score (using a qualitative scale) or rank alternatives based on estimates of energy, chemical and material, water, and land use. The following sections provide guidance on how to: 1) collect and use quantitative data, 2) qualitatively score alternatives based on estimated resource requirements, and 3) rank alternatives based on estimated resource requirements.

It is important to note that data collected on energy, chemicals and materials, water, and land are consistent across the alternatives being assessed. If quantitative data are collected on the energy use of one system, quantitative data should be collected on the energy use of all systems in the assessment. Consistency in the type of data that are used to compare systems is important because the comparison is based on relative SLCA results. For example, after conducting SLCAs on multiple systems, the SLCA results of these systems will be compared on a relative basis to identify the most sustainable materiel solution. In this case, quantified impacts, in terms of absolute value, are not necessary for this relative comparison. Conversely, the relative difference, in terms of percentage points, between alternatives within a particular impact category should be emphasized. For this reason, maintaining consistency in the type of data collected and used in the assessment, including assumptions that are made, is crucial for achieving the highest level of precision.

NOTE: There may be situations where quantitative data are available for some of the resources, but not for others. For example, quantitative data may be available for energy use, but not for chemicals and materials or water. In this situation, quantitative data can be used for energy, scoring can be used for chemicals and materials, and ranking can be used for water. Quantitative data, scoring, and ranking can be used in conjunction as long as the same data type for a given resource is used across all alternatives being assessed. This flexibility is a major advantage of the SLCA developed for DoD.

6.4.6.1 Quantitative Data. Quantitative life cycle data on energy, chemicals and materials, water, and land use should be continually collected throughout all phases of acquisition, including the systems engineering process, manufacturing and productions, deployment, sustainment and end of life phases. As data is collected throughout the life of the system, it is recommended that this data be stored in a central repository that is accessible for use in future SLCAs. In general, it is recommended that previous SLCAs be updated with newly acquired data to improve results for that specific system and future system acquisitions. Updating these assessments also will provide Program Offices with the ability to compare the program's actual impacts with the SLCA estimated impacts.

When conducting a SLCA, evaluators should use quantitative legacy data whenever possible. If verifiable quantitative data from legacy system is used, evaluators shall ensure that the function and operation of the legacy system closely resembles the proposed function and operation for the alternative being assessed.

6.4.6.2 Score. When data are not available or too costly and time consuming to collect from a similar legacy system, evaluators can assess each alternative according to a qualitative scale. A qualitative scale is not based on actual data, but should represent both the order of performance (i.e., best to worst), as well as an estimated magnitude of difference in performance amongst the alternatives for a given resource. The structure of these qualitative scales can differ across metrics. It is important to note that two or more alternatives can have the same qualitative score if such alternatives perform the same within a given metric. Such qualitative scales will typically be bounded between 0% to 100% or 0 to 10; however, the bounds of the scale can be set at any level as long as consistently used within a particular input type (i.e. energy, chemicals and materials, water and land) and across all alternatives.

6.4.6.3 Ordinal Ranking. If evaluators are unable to estimate the general magnitude of difference in resource use between two alternatives such as energy consumption, evaluators should rank those alternatives according to the best through worst performing for that given resource. It is important to note that when assigning an ordinal rank, the magnitude of difference amongst alternatives will not be captured. Evaluators should also note that two or more alternatives can have the same ordinal rank if those alternatives consume the same amount of a given resource. If this is the case, the next best option shall assume the next numerical rank. For example, if two alternatives both rank as best (i.e., 1), the next best option, which is the third assessed alternative, will assume the rank of 2 (see Table 4).

TABLE 4. Example of ordinal ranking

	Rank
Alternative A	1
Alternative B	1
Alternative C	2
Alternative D	3
Alternative E	4
Alternative F	4
Alternative G	5

6.5 Assessing Mission, Human Health and Environmental Impacts. System life cycle data on energy, chemicals and materials, water, land, and noise are used to assess impacts to mission, human health and the environment. There are a total of 23 impact categories (Table 5). These categories are grouped into six general areas of concern: (1) Mission, (2) Human Health, (3) Ecosystem Health, (4) Air, (5) Water, and (6) Land.

TABLE 5. Impact categories organized by areas of concern

Areas of Concern	Impact Categories
Mission	Fossil Fuel Depletion
	Energy Source Reliability
	C&M Availability
	Recovery Potential
	Total Water Use
Human Health	Respiratory Effects
	Carcinogens
	Non-carcinogens
	Ionizing Radiation
	Human Noise
Ecosystem Health	Freshwater Ecotoxicity

Areas of Concern	Impact Categories
	Terrestrial Ecotoxicity
	Marine Ecotoxicity
	Ecosystem Noise
Air	Global Warming Potential
	Ozone Depletion
	Smog
Water	Water Recovery Efficiency
	Water Loss Efficiency
	Fit-for-Use
	Water Degradation
	Water Scarcity
Land	Land Degradation

There are two approaches for assessing impacts based on the gathered input inventory data. The first approach is to use the SLCA tool as described in 6.5.1 of this guidance. The second approach is to assess impacts manually by using the scoring factors provide in Appendix C. Guidance on how to use the scoring factors and manually calculate human health and environmental impacts is provided in 6.5.2.

6.5.1 Assessing impacts using the SLCA tool. The SLCA tool and directions on how to use the tool is available at (http://denix.osd.mil/esohacq/). The SLCA tools automatically enters the appropriate impact data and calculates the relative scores for alternatives, then provides a decision tool in the form of a spider-web diagram that compares impact categories for each alternative.

6.5.2 Assessing impacts manually using the Scoring Factors. If not using the SLCA tool, the following sections provide guidance on how to use scoring factors to calculate impacts from resource consumption, as identified in the input inventory (see 6.4). Guidance on how to calculate the impact is provided below for each impact category.

6.5.2.1 Fossil Fuel Depletion. The use of fossil fuels, which are fuels that cannot be replenished, impacts the DoD's mission by reducing the future supply of energy. The goal of this impact category is to ensure that evaluators consider the amount of fossil fuels used by each evaluated alternative, and that renewable sources of energy be utilized when possible. For the purpose of scoring alternatives in this impact category, Appendix C provides scoring factors (SF_t) for each energy type t recorded in 6.4.1. These scoring factors describe and account for the expected demand for a particular fossil fuel compared to that fuel's available reserves. These factors use the energy content for a gallon of crude oil, which also applies to all crude oil by-products, as a baseline. Renewable and non-fossil fuels all have scoring factors of zero because there is no fossil fuel depletion potential.

To calculate the fossil fuel depletion score for alternative x (FFD_x), evaluators should sum the results of multiplying the quantity of each energy type used by the alternative (Q_t) by that type's scoring factor (SF_t). Q_t should be recorded in units designated in Appendix C, or in accordance with 6.4.6 when quantitative data is not available, and should include both direct and indirect energy. Equation 1 summarizes this calculation below.

$$(1) \quad FFD_x = \sum_{t=1}^{n} Q_t \times SF_t$$

Within this metric, alternatives with a lower FFD_X have lower risk of depleting fossil fuels, and thus, should be preferred over other alternatives with higher scores.

6.5.2.2 Energy Source Reliability. Reliable sources of energy are critical for meeting the DoD's mission. The goal of this impact category is to ensure that evaluators assess the overall reliability of the sources of energy that will be used throughout the life cycle of the systems or components evaluated and give preference to alternatives that use energy from more reliable sources. Evaluators should compare alternatives based on the overall reliability, in terms of supply chain risk, of all sources of energy recorded under the guidance of 6.4.1.

An energy source is considered reliable if that source presents a low source, economic, and resource risk. Each type of risk is summarized below:

a. Source risk. The source risk for energy type *t* (S_t) occurs when that energy type is extracted outside of a U.S controlled territory or within a politically unfriendly or unstable sovereignty.
b. Economic risk. The economic risk for energy type *t* (E_t) occurs when that energy type is potentially cost prohibitive or possesses a risk of substantial cost increase.
c. Resource risk. The resource risk for energy type *t* (R_t) occurs when that energy type is subject to supply interruptions caused by lack of resource availability.

Using the above criteria, alternatives presenting a low reliability risk should be considered superior, and thus, should be preferred over other alternatives. To assess the total reliability risk across those three criteria, evaluators shall first assign a risk score to each criterion in accordance with Table 6 below.

TABLE 6. Risk level scores

Risk Level	Score
None	0
Very Low	1
Low	2
Medium	3
High	4
Very High	5

Once each criterion for each energy type has been scored, evaluators should calculate the weighted reliability score for alternative x (WRS_x). This score is calculated by summing S_t, E_t, and R_t and weighting that combined score by a weighting factor. This weighting factor is calculated by dividing the total amount of energy consumed by energy type t (TE_t), in British thermal units (Btu), by the total amount of energy consumed by alternative X (TE_x) across all energy types (also recorded in Btu). To convert this score into a zero-to-ten scale, the resulting summation of those results should be multiplied by 2. See Equation 2 below.

$$(2) \quad WRS_x = 2 \times \sum_{t=1}^{n} (S_t + E_t + R_t) \times \left(\frac{TE_t}{TE_x}\right)$$

Within this metric, alternatives with a lower WRS_X have lower reliability risk, and thus, should be preferred over other alternatives with higher scores.

6.5.2.3 C&M Availability. Many defense systems and components utilize chemicals and materials that present risk in terms of availability for future supply needs. The goal of this impact category is to ensure that evaluators consider the use of available chemicals and materials, in terms of supply chain risk, across the system's or component's life cycle and give preference to alternatives that utilize less supply-limited chemicals and materials. Evaluators should compare alternatives based on the overall availability of all input chemicals and materials recorded under the guidance of 6.4.2. When comparing alternatives according to the availability of the chemicals and materials needed by a particular system or component, evaluators should give special attention to chemicals and materials critical to mission.

A chemical or material is considered reliable if it presents a low source, economic, and resource risk. Each type of risk is summarized below:

a. Source risk. The source risk for chemical or material t (S_t) occurs when that chemical or material is extracted outside of, or supplied by, a U.S controlled territory or within a politically unfriendly or unstable sovereignty. For chemicals and materials only, a source risk can also occur when the supply of that chemical or material is restricted by policy; such as government regulation (local, regional, state, national, and international) or a supplier's corporate policy.
b. Economic risk. The economic risk for chemical or material t (E_t) occurs when that chemical or material is potentially cost prohibitive or possesses a risk of substantial cost increase.
c. Resource risk. The resource risk for chemical or material t (R_t) occurs when that chemical or material is subject to supply interruptions caused by lack of resource availability.

Using the above criteria, alternatives presenting a low availability risk should be considered superior, and thus, should be preferred over other alternatives. To assess the total availability risk across those three criteria, evaluators shall first assign a risk score to each criterion in accordance with Table 7 below.

TABLE 7. Risk level scores

Risk Level	Score
None	0
Very Low	1
Low	2
Medium	3
High	4
Very High	5

Once each criterion for chemical or material has been scored, evaluators should calculate the weighted availability score for alternative x (WAS_x). This score is calculated by summing S_t, E_t, and R_t and weighting that combined score by a weighting factor. This weighting factor is calculated by dividing the total mass of input chemical or material t (TCM_t), in kilograms (kg), by the total mass of all input chemicals and materials consumed by alternative x (TCM_x) (also recorded in kg). To convert this score into a zero-to-ten scale, the resulting summation of those results should be multiplied by 2. See Equation 3 below.

$$(3) \quad WAS_x = 2 \times \sum_{t=1}^{n} (S_t + E_t + R_t) \times \left(\frac{TCM_t}{TCM_x}\right)$$

Within this metric, alternatives with a lower WAS_X have lower availability risk, and thus, should be preferred over other alternatives with higher scores.

6.5.2.4 Recovery Potential. When utilizing chemicals and materials, especially those with availability risk identified under the guidance in 6.5.2.3, recovering those chemicals and materials for the purpose of reuse—either in that system or component, or in other systems or components—can greatly increase the sustainability of a system or component. The goal of this impact category is to ensure that evaluators consider the use of recoverable chemicals and materials throughout the system's or component's life cycle and give preference to alternatives with a higher recovery potential. Evaluators should assess each alternative to determine the mass of chemicals and materials that can be recovered for future use as resources. The process of capturing chemicals and materials for reuse, repurpose, or recycle ultimately diverts these materials from entering the waste stream, and thus, enhances the sustainability of that system or component.

Each alternative's (x) total chemical and material recovery potential score (RPS_x) represents the aggregated mass of chemicals and materials that can be recovered for future use as input resources; either for that particular system or component, or for other systems or components. An alternative's recovery potential can be calculated as the summation of the recovery potential of selected chemicals and materials that compose a system or component. The chemicals and materials selected for inclusion in the recovery potential calculation should account for legislative, regulatory, statutory, and DoD policy requirements for chemicals and materials recovery. For those chemicals and materials not covered by legislative, regulatory, statutory, or DoD policy recovery requirements, the evaluation team may select for inclusion those chemicals and materials that meet *de minimis* criteria (e.g., quantity and type of chemicals and materials).

Chemicals and materials that are precious, strategic or mission critical, or rare in supply should always be considered regardless of the *de minimis* criteria chosen.

RPS_x can be calculated as a ratio of the summation of all chemical and material mass recovered for select chemical or material t (R_t) divided by the total chemical and material mass (T_x) used by the that alternative (x). This ratio is then subtracted from one (see Equation 4).

$$(4) \quad RPS_x = 1 - \left(\frac{\sum_{t=1}^{n} R_t}{T_x}\right)$$

It is important to note that for this metric, a smaller RPS_x represents a better recovery potential because an alternative with a higher recovery potential has a lower impact footprint. This proportion shall be calculated in terms of the functional unit (see 6.1).

6.5.2.5 Total Water Use. The use of water impacts the DoD's mission because water is often difficult to supply and transport in areas where water from local resources is unavailable. The goal of this impact category is to ensure that evaluators consider how much water, in terms of direct and indirect water, is used by the system or component across all activities throughout its life cycle and give preference to alternatives that use the least volume of water. When calculating the total water used (W_x) by an alternative (x), evaluators should sum all quantities (Q_t) of water for each activity type t, as recorded under the guidance of 6.4.3. Equation summarizes this calculation below.

$$(5) \quad W_x = \sum_{t=1}^{n} Q_t$$

Within this metric, alternatives with a lower W_X use less water, and thus, should be preferred over other alternatives with higher scores.

6.5.2.6 Respiratory Effects. The combustion of fuels for energy, either directly at the source or indirectly through the use of electricity, leads to criteria air pollutants that can lead to negative human respiratory impacts, such as asthma and allergic reactions. The goal of this impact category is to ensure that evaluators consider these resulting emissions and their impact on human health for each evaluated alternative, and limit those emissions when possible. For the purpose of scoring alternatives in this impact category, Appendix C provides scoring factors (SF_t) for each energy type t recorded in 6.4.1. These scoring factors describe and account for the transport of criteria air pollutants to the exposed population via air exposure routes and the change in probability to respiratory conditions due to the lifetime intake.

To calculate the respiratory effects score for alternative x (RES_x), evaluators should sum the results of multiplying the quantity of each energy type used by the alternative (Q_t) by that type's scoring factor (SF_t). Q_t should be recorded in units designated in Appendix C, or in accordance with 6.4.6 when quantitative data is not available, and should include both direct and indirect energy. Equation 6 summarizes this calculation below.

$$(6) \quad RES_x = \sum_{t=1}^{n} Q_t \times SF_t$$

Within this metric, alternatives with a lower RES_X have lower potential for creating respiratory effects, and thus, should be preferred over other alternatives with higher scores.

6.5.2.7 Carcinogens. Hazardous chemical emissions to air, soil, and water present human toxicity concerns. The goal of this impact category is to ensure that evaluators identify the use of hazardous chemicals that could significantly increase the probability of cancer given elevated levels of exposure, and consider system or component designs that eliminate the use of these chemicals. For the purpose of scoring alternatives in this impact category, Appendix C provides scoring factors (SF_t) for each chemical *t* recorded in 6.4.2. These scoring factors describe toxicity impact potential and account for the transport of these emissions from the environmental compartments (i.e., air, soil, water) to the exposed population via these exposure routes and the change in disease probability due to the lifetime intake. These scoring factors are used to represent the steps along the cause-effect chain starting with the emission of the chemicals and materials that occur in the life cycle of the system, followed by the fate and transport through the environment, exposure to humans, and the resulting effects on the exposed populations. A scoring factor for a chemical or material represents that chemical's potency – its potential to have adverse impacts for humans.

To calculate the cancer score for alternative x (CS_x), evaluators should sum the results of multiplying the quantity of each chemical used by the alternative (Q_t) by that chemical's scoring factor (SF_t). Q_t should be recorded in units designated in Appendix C, or in accordance with 6.4.6 when quantitative data is not available, and should include both direct and indirect energy. Equation 7 summarizes this calculation below.

$$(7) \quad CS_x = \sum_{t=1}^{n} Q_t \times SF_t$$

Within this metric, alternatives with a lower CS_X have lower toxicity potential, and thus, should be preferred over other alternatives with higher scores.

6.5.2.8 Non-Carcinogens. Hazardous chemical emissions to air, soil, and water present human toxicity concerns. The goal of this impact category is to ensure that evaluators identify the use of hazardous chemicals that could significantly increase the probability of non-cancer diseases given elevated levels of exposure, and consider system or component designs that eliminate the use of these chemicals. For the purpose of scoring alternatives in this impact category, Appendix C provides scoring factors (SF_t) for each chemical *t* recorded in 6.4.2. These scoring factors describe toxicity impact potential and account for the transport of these emissions from the environmental compartments (i.e., air, soil, water) to the exposed population via these exposure routes and the change in disease probability due to the lifetime intake. These scoring factors are used to represent the steps along the cause-effect chain starting with the emission of the chemicals and materials that occur in the life cycle of the system, followed by the fate and transport through the environment, exposure to humans, and the resulting effects on the exposed populations. A scoring factor for a chemical or material represents that chemical's potency – its potential to have adverse impacts for humans.

To calculate the non-cancer score for alternative x (NCS_x), evaluators should sum the results of multiplying the quantity of each chemical used by the alternative (Q_t) by that chemical's scoring factor (SF_t). Q_t should be recorded in units designated in Appendix C, or in accordance with 6.4.6 when quantitative data is not available, and should include both direct and indirect energy. Equation 8 summarizes this calculation below.

$$(8) \quad NCS_x = \sum_{t=1}^{n} Q_t \times SF_t$$

Within this metric, alternatives with a lower NCS_X have lower toxicity potential, and thus, should be preferred over other alternatives with higher scores.

6.5.2.9 Ionizing Radiation. The use of radioactive material for nuclear energy, such as uranium, can lead to negative human health impacts if exposure to ionizing radiation, either at the initial source of use or as improperly controlled waste, is not controlled. The goal of this impact category is to ensure that evaluators consider all potential exposures and their impact on human health for each evaluated alternative, and limit such exposure when possible. For the purpose of scoring alternatives in this impact category, Appendix C provides scoring factors (SF_t) for uranium use t recorded in 6.4.1. The scoring factors describe and account for the transport, dispersion, and deposition of radioactive releases of the isotope Uranium-235 and the inhalation or ingestion of water or food contaminated by this material.

To calculate the ionizing radiation score for alternative x (IRS_x), evaluators should sum the results of multiplying the quantity of each energy type used by the alternative (Q_t) by that type's scoring factor (SF_t). Q_t should be recorded in units designated in Appendix C, or in accordance with 6.4.7.2 when quantitative data is not available, and should include both direct and indirect energy. Equation 9 summarizes this calculation below.

$$(9) \quad IRS_x = \sum_{t=1}^{n} Q_t \times SF_t$$

Within this metric, alternatives with a lower IRS_X have lower potential for creating respiratory effects, and thus, should be preferred over other alternatives with higher scores.

6.5.2.10 Human Noise. Systems and components that emit highs level of noise can be detrimental to human health. Unlike other impacts in this guidance, noise does not result from energy, chemical and material, water or land inputs. Instead, noise is a resulting output of the system itself. The potential impact from noise is determined by considering the population of various exposure groups (t) and the level of exposure (E_t)—including duration if data are available—to the noise emission source at the distance (d) from which each population is from the noise emission source. Exposure should be measured in the most applicable units, usually in decibel A-weighting (dBA). Each alternative's (x) noise impact (N_x) to human health is therefore calculated as the summation of each population's level of noise exposure at that population's distance from the source, weighted by the population's size (P_t). Equation 10 summarizes this calculation below.

$$(10) \quad N_x = \sum_{t=1}^{n} P_t \times E_t$$

It is important to note that if the population size (P_t) for a given exposure group (t) is unknown, evaluators should replace P_t with the number one for all exposure groups. In this case, only the exposure level at the specified distance will be recorded.

Within this metric, alternatives with a lower N_X present a lower potential for noise impacts, and thus, should be preferred over other alternatives with higher scores.

6.5.2.11 Freshwater Ecotoxicity. Hazardous chemical emissions to freshwater ecosystems present toxicity concerns for wildlife residing in that environmental compartment. The goal of this impact category is to ensure that evaluators identify the use of hazardous chemicals that could significantly increase the probability of ecological toxicity in freshwater environments given elevated levels of exposure, and consider system or component designs that eliminate the use of these chemicals. For the purpose of scoring alternatives in this impact category, Appendix C provides scoring factors (SF_t) for each chemical *t* recorded in 6.4.2. These scoring factors describe toxicity impact potential and account for the transport of these emissions from the environmental compartments (i.e., air, soil, water) to the exposed population via these exposure routes and the change in disease probability due to the lifetime intake. These scoring factors are used to represent the steps along the cause-effect chain starting with the emission of the chemicals and materials that occur in the life cycle of the system, followed by the fate and transport through the environment, exposure to freshwater wildlife, and the resulting effects on the exposed populations. A scoring factor for a chemical or material represents that chemical's potency – its potential to have adverse impacts for freshwater species.

To calculate the freshwater ecotoxicity score for alternative x (FES_x), evaluators should sum the results of multiplying the quantity of each chemical used by the alternative (Q_t) by that chemical's scoring factor (SF_t). Q_t should be recorded in units designated in Appendix C, or in accordance with 6.4.6 when quantitative data is not available, and should include both direct and indirect energy. Equation 11 summarizes this calculation below.

$$(11) \quad FES_x = \sum_{t=1}^{n} Q_t \times SF_t$$

Within this metric, alternatives with a lower FES_X have lower toxicity potential, and thus, should be preferred over other alternatives with higher scores.

6.5.2.12 Terrestrial Ecotoxicity. Hazardous chemical emissions to terrestrial ecosystems present toxicity concerns for wildlife residing in that environmental compartment. The goal of this impact category is to ensure that evaluators identify the use of hazardous chemicals that could significantly increase the probability of ecological toxicity in terrestrial environments given elevated levels of exposure, and consider system or component designs that eliminate the use of these chemicals. For the purpose of scoring alternatives in this impact category, Appendix C provides scoring factors (SF_t) for each chemical *t* recorded in 6.4.2. These scoring factors describe toxicity impact potential and account for the transport of these emissions from the environmental compartments (i.e., air, soil, water) to the exposed population via these exposure routes and the change in disease probability due to the lifetime intake. These scoring factors are used to represent the steps along the cause-effect chain starting with the emission of the chemicals and materials that occur in the life cycle of the system, followed by the fate and transport through the environment, exposure to terrestrial wildlife, and the resulting effects on the exposed populations. A scoring factor for a chemical or material represents that chemical's potency – its potential to have adverse impacts for terrestrial species.

To calculate the terrestrial ecotoxicity score for alternative x (TES_x), evaluators should sum the results of multiplying the quantity of each chemical used by the alternative (Q_t) by that chemical's scoring factor (SF_t). Q_t should be recorded in units designated in Appendix C, or in accordance with 6.4.6 when quantitative data is not available, and should include both direct and indirect energy. Equation 12 summarizes this calculation below.

$$(12) \quad TES_x = \sum_{t=1}^{n} Q_t \times SF_t$$

Within this metric, alternatives with a lower TES_X have lower toxicity potential, and thus, should be preferred over other alternatives with higher scores.

6.5.2.13 Marine Ecotoxicity. Hazardous chemical emissions to marine ecosystems present toxicity concerns for wildlife residing in that environmental compartment. The goal of this impact category is to ensure that evaluators identify the use of hazardous chemicals that could significantly increase the probability of ecological toxicity in marine environments given elevated levels of exposure, and consider system or component designs that eliminate the use of these chemicals. For the purpose of scoring alternatives in this impact category, Appendix C provides scoring factors (SF_t) for each chemical *t* recorded in 6.4.2. These scoring factors describe toxicity impact potential and account for the transport of these emissions from the environmental compartments (i.e., air, soil, water) to the exposed population via these exposure routes and the change in disease probability due to the lifetime intake. These scoring factors are used to represent the steps along the cause-effect chain starting with the emission of the chemicals and materials that occur in the life cycle of the system, followed by the fate and transport through the environment, exposure to marine wildlife, and the resulting effects on the exposed populations. A scoring factor for a chemical or material represents that chemical's potency – its potential to have adverse impacts for marine species.

To calculate the marine ecotoxicity score for alternative x (MES_x), evaluators should sum the results of multiplying the quantity of each chemical used by the alternative (Q_t) by that chemical's scoring factor (SF_t). Q_t should be recorded in units designated in Appendix C, or in accordance with 6.4.7.2 when quantitative data is not available, and should include both direct and indirect energy. Equation 13 summarizes this calculation below.

$$(13) \quad MES_x = \sum_{t=1}^{n} Q_t \times SF_t$$

Within this metric, alternatives with a lower MES_X have lower toxicity potential, and thus, should be preferred over other alternatives with higher scores.

6.5.2.14 Ecosystem Noise. Systems and components that emit highs level of noise can be detrimental to marine mammals and other wildlife. Unlike other impacts in this guidance, noise does not result from energy, chemical and material, water or land inputs. Instead, noise is a resulting output of the system itself. The potential impact from noise is determined by considering the population of various exposure groups (t) and the level of exposure (E_t)—including duration if data are available—to the noise emission source at the distance (d) from which each population is from the noise emission source. Exposure should be measured in the most applicable units, usually in decibel A-weighting (dBA). Each alternative's (x) noise impact (N_x) to human health is therefore calculated as the summation of each population's level of noise exposure at that population's distance from the source, weighted by the population's size (P_t). Equation 14 summarizes this calculation below.

$$(14) \quad N_x = \sum_{t=1}^{n} P_t \times E_t$$

It is important to note that if the population size (P_t) for a given exposure group (t) is unknown, evaluators should replace P_t with the number one for all exposure groups. In this case, only the exposure level at the specified distance will be recorded.

Within this metric, alternatives with a lower N_X present a lower potential for noise impacts, and thus, should be preferred over other alternatives with higher scores.

6.5.2.15 Global Warming. The combustion of fuels for energy, either directly at the source or indirectly through the use of electricity, leads to air pollutants that cause global warming. The goal of this impact category is to ensure that evaluators consider these resulting emissions and their impact on global warming for each evaluated alternative, and limit those emissions when possible. For the purpose of scoring alternatives in this impact category, Appendix C provides scoring factors (SF_t) for each energy type *t* recorded in 6.4.1. These scoring factors describe and account for emission of air pollutants and their incremental contribution to global warming.

To calculate the global warming potential score for alternative x (GWP_x), evaluators should sum the results of multiplying the quantity of each energy type used by the alternative (Q_t) by that type's scoring factor (SF_t). Q_t should be recorded in units designated in Appendix C, or in accordance with 6.4.6 when quantitative data is not available, and should include both direct and indirect energy. Equation summarizes this calculation below.

$$(15) \quad GWP_x = \sum_{t=1}^{n} Q_t \times SF_t$$

Within this metric, alternatives with a lower GWP_X have lower global warming potential, and thus, should be preferred over other alternatives with higher scores.

6.5.2.16 Ozone Depletion. The use of substances like chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and halogens for applications such as refrigerants and aerosols contribute to ozone depletion. The goal of this impact category is to ensure that evaluators consider these resulting emissions and their impact on ozone depletion for each evaluated alternative, and limit those emissions when possible. For the purpose of scoring alternatives in this impact category, Appendix C provides scoring factors (SF_t) for each energy type *t* recorded in 6.4.1. These scoring factors describe and account for emission of air pollutants and their incremental contribution towards the destruction of the stratospheric ozone layer.

To calculate the ozone depletion potential score for alternative x (ODP_x), evaluators should sum the results of multiplying the quantity of each ozone depleting substance used by the alternative (Q_t) by that substance's scoring factor (SF_t). Q_t should be recorded in units designated in Appendix A, or in accordance with 6.4.6 when quantitative data is not available, and should include both direct and indirect energy. Equation 16 summarizes this calculation below.

$$(16) \quad ODP_x = \sum_{t=1}^{n} Q_t \times SF_t$$

Within this metric, alternatives with a lower ODP_X have lower ozone depletion potential, and thus, should be preferred over other alternatives with higher scores.

6.5.2.17 Smog. The combustion of fuels for energy, either directly at the source or indirectly through the use of electricity, leads to air pollutants that cause tropospheric smog. The goal of this impact category is to ensure that evaluators consider these resulting emissions and their impact on smog formation for each evaluated alternative, and limit those emissions when possible. For the purpose of scoring alternatives in this impact category, Appendix C provides scoring factors (SF_t) for each energy type *t* recorded in 6.4.1. These scoring factors describe and account for emission of air pollutants and their incremental contribution towards the formation of tropospheric smog.

To calculate the smog potential score for alternative x (SP_x), evaluators should sum the results of multiplying the quantity of each energy type used by the alternative (Q_t) by that type's scoring factor (SF_t). Q_t should be recorded in units designated in Appendix C, or in accordance with 6.4.6 when quantitative data is not available, and should include both direct and indirect energy. Equation 17 summarizes this calculation below.

$$(17) \quad SP_x = \sum_{t=1}^{n} Q_t \times SF_t$$

Within this metric, alternatives with a lower SP_X have lower smog potential, and thus, should be preferred over other alternatives with higher scores.

6.5.2.18 Water Recovery Efficiency. From an input perspective, the recovery of water for reuse assures increased input efficiency of water use for a system or component. The goal of this impact category is to ensure that evaluators give preference to systems or components that recover and reuse a large proportion of the total volume of input water, both direct and indirect, for future DoD use either from that the same system or component or another outside the boundaries of the study. In accordance with Figure 6 in 6.4.3, evaluators should compare alternatives according to the water recovery efficiency, which is the ratio of water withdrawn from recovered sources ($B + C$) to the total volume of water used by and in support and sustainment of the system or component ($A + B + C$). Evaluators should assess alternatives based on the ability to use recovered, reused, or recycled water in relation to the total volume of water required by the system or component.

It is important to note that for this metric, a smaller water recovery efficiency represents a greater proportion of direct and indirect water being recovered for reuse, which implies a lower impact footprint. Thus, to present this efficiency in terms of footprint that is consistent with all other scoring metrics outlined in this document (i.e., greater value equating to a larger footprint), evaluators should subtract this efficiency from one (see Equation 18) to get the inverse water recovery efficiency (IR_x). Using this approach, the alternative with the smallest IR_x, has the smallest total water use footprint and is the alternative that recovers and reuses the largest portion of water used during system or component operation and support and sustainment activities. Evaluators should favor alternatives with a smaller IR_x.

$$(18) \quad IR_x = 1 - \left(\frac{B + C}{A + B + C}\right)$$

6.5.2.19 Water Loss Efficiency. From an output perspective, the loss of water from a system or component through transformations such as evaporation and transpiration prevent the return of water to its original source, which can be detrimental to freshwater ecosystems and local communities. The goal of this impact category is to ensure that evaluators give preference to systems or components that minimize the total volume of output water, both direct and indirect, lost to transformations. In accordance with Figure 6 in 6.4.3, evaluators should compare alternatives according to the water loss efficiency (L_x), which is the ratio of water lost to transformation (F) to the total volume of water used by and in support and sustainment of the system or component ($C + D + E + F$). Equation 19 summarizes this calculation below. Evaluators should favor alternatives with a smaller L_x.

$$(19) \quad L_x = 1 - \left(\frac{F}{C + D + E + F}\right)$$

6.5.2.20 Fit-for-Use. The goal of this impact category is to ensure that evaluators give preference to alternatives for which the quality of the source of water used closely matches the required quality needed for each application or activity. In determining this score, evaluators should compare alternatives according to how close the quality of the source water used directly by the system or component and in support or sustainment activities matches the required quality to perform those activities. The more fit-for-use, meaning the water quality of the source closely resembles the water quality required for use, the water source is, the less treatment is needed to improve lower quality water and the less wasteful the system or component is when the source quality is of higher quality. The probability of increased energy consumption or wasted clean drinking water increases as the variance between source and required quality increases. Thus, alternatives that rely on water sources that provide a quality of water that closely matches the water quality needed by the use shall be favored over systems or components that rely on water sources that either; 1) require treatment of the water in order to achieve the water quality needed by the use; or 2) utilize a water source of higher quality than what is required.

Fit-for-Use (FFU_x) is calculated by first identifying all the potential uses of water that an alternative requires during its life cycle. When data are available, evaluators should record the volume of water required by the system or component (V_i) per type of use (i). This may already have been calculated in the Fit-for-Use metric and may be used again for this metric.

Evaluators shall then assess the water quality requirements needed for each type of use according to the water quality categories presented in Table 8. There are 11 water quality categories described in Table 8 that are ranked from highest quality to lowest quality. Using these water category designations, evaluators should assign a designation letter to both the source quality, which is represented by the vertical axis in Figure 7, and the required quality, which is represented by the horizontal axis in Figure 7. Evaluators shall then plot the water use for each alternative on Figure 7. Evaluators should note that an alternative may use different sources of water and should provide a separate plot for each source used by each alternative.

The fit-for-use score ($FFUs_x$) for a single plot (i.e., single source for a given alternative) is determined by the score designated in Figure 7 to the gradient plane in which that plot falls within. A score of 0 means that the source water quality and the water quality required by the use are perfectly matched and is the best possible score an alternative can earn. A score of 10 means that the source water quality and water quality needed by the use are drastically different implying that either: 1) intensive water treatment is required; or 2) ultrapure water is being used for an application where the water quality of untreated waste water would suffice. A score of 10 is the worst possible score an alternative can earn.

Once the fit-for-use score is recorded for each source used by a given alternative, evaluators should translate those scores into a weighted average by multiplying $FFUs_x$by the percentage of total water used by that system or component that V_x comprises (see Equation 20 and Figure 6).[8]

[8] Total water used is the sum of total direct water ($A_1 + B_1 + C_1$ or $C_1 + D_1 + E_1 + F_1$) and total indirect water ($A_2 + B_2 + C_2$ or $C_2 + D_2 + E_2 + F_2$), see Figure 6.

$$(20)\quad FFU_x = \sum_{i=1}^{n} \frac{V_i}{(A+B+C)} \times FFUs_x = \sum_{i=1}^{n} \frac{V_i}{(C+D+E+F)} \times FFUs_x$$

TABLE 8. Water quality categories and descriptions

Category	Category Label	Water Quality Description	Water Quality Parameters	Example Uses
A	Ultrapure	Distilled or highly purified water that contains no physical, chemical, or microbial impurities	Conductivity≤ 5 µS/m; TDS ≤ 10 mg/L	Process water for high purity applications
B	Drinking water (potable water)	Water that is considered safe to drink as defined by the health-based standards in the Safe Drinking Water Act	Absence of coliform bacteria, turbidity ≤ 0.3 NTU, below Maximum Contaminant Level (MCL) for nitrate, nitrite, metals, fluoride, and other regulated parameters	Most uses of water including but not limited to drinking water
C	Non-potable water	Water that does not meet the requirements of the Safe Drinking Water Act	Physical, chemical, or microbial parameters including turbidity, nutrients, microbial indicators	Irrigation, industrial process water, cleaning, cooling water
D	Captured Rain water	Water that is captured during storm events and stored without exposure to environmental contaminants	Conductivity, turbidity	Most uses of water, but would require additional treatment before being used for potable water
E	Storm water	Water that originates during precipitation events and contacts roadways, urban and rural landscapes, and agricultural facilities. Depending on local land-use patterns and the extent of pervious surfaces, some of the water percolates into the ground and the remaining water is either captured or runs off into local surface water systems.	Sediments, fuel components, pathogens, nutrients, and other chemical constituents depending on the intensity of a storm event and land use patterns	Irrigation, groundwater recharge, some industrial uses but might require additional treatment
F	Gray water	Water that has been used for most in-building or shipboard uses except toilet flushing	Pathogens, soaps/surfactants, and organic chemicals including those found in flame retardants and insect repellants.	Irrigation, toilet-flushing, cleaning; additional treatment might be required depending on how the water was used previously
G	Reclaimed (recycled) water	Water recovered from municipal wastewater that has been treated to control pathogens and solids.	Pathogens, nutrients, salts, chemical contaminants	Non-potable and indirect potable applications, depending on level of treatment provided

Category	Category Label	Water Quality Description	Water Quality Parameters	Example Uses
H	Brackish water	Water that contains between 500 and 3,000 ppm of total dissolved solids. Typically found in estuaries, coastal groundwater systems, and deep (>1,000 ft) groundwater	Conductivity, hardness, metals, nutrients, pathogens, corrosivity	Some non-potable applications including industrial process water, cooling water; other applications might require additional treatment
I	Salt water	Water that contains over 3,000 ppm of total dissolved solids	Conductivity, hardness, metals, nutrients, pathogens, algae	Cooling water; salt water is more dense than fresh water and also has a lower capacity to store dissolved oxygen
J	Industrial wastewater	Used water from industrial applications including process water, washwater, and cooling water blowdown	Pathogens, chemical contaminants, sediments, nutrients	Possible to reuse or recycle within a specific industrial application or augment water for other (lower quality) water use needs onsite
K	Untreated wastewater	Used water discharged from homes, business, cities, industry, and agriculture	Pathogens, chemical contaminants, sediments, nutrients	Water that poses a potential health and environmental risk due to potential prevalence of pathogens and toxic constituents
L	Radioactive Wastewater	Water from activities or events known to have radioactive characteristics	Radioactive compounds such as Cesium-137, Americium-241, Uranium 234,235, and 238, Plutonium 238,239/240, Radium 226 and Strontium 90	Water posing health and environmental risk due to: (1) the presence of radioactive isotopes (includes sources such as extractive activities); or (2) water disposed post terrorist activity through a Radiological Dispersion Devise (RDD) such as a “dirty bomb” (includes radioactive contamination of water supply or wash waters from cleanup activities from such events)

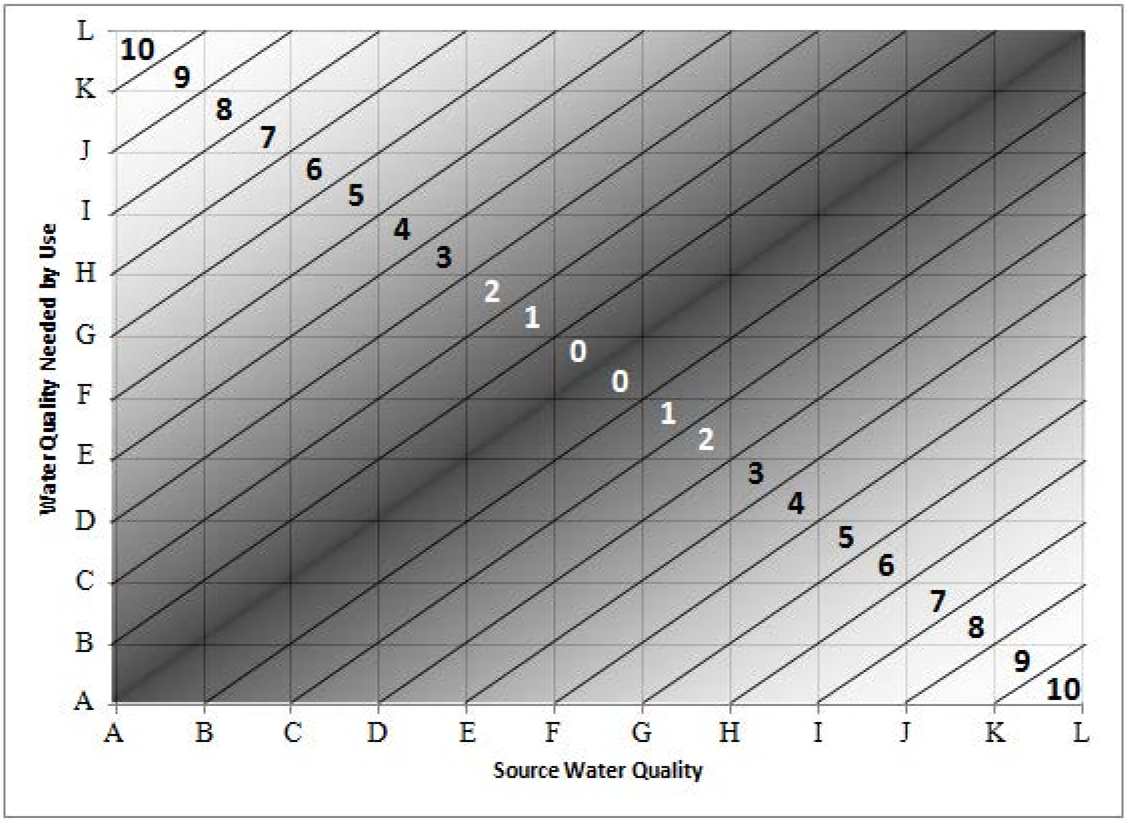

FIGURE 7. Fit-for-use scoring diagram

6.5.2.21 Water Degradation. The goal of this impact category is to ensure that evaluators assess whether an alternative degrades any water, direct or indirect, used by the system or component. Another goal of this impact category is to ensure that evaluators assess the level of degradation that occurs and give preference to alternatives that have a minimum quality variance between water inputs and outputs. Alternatives with lower variance shall be favored over systems or components with higher variance. Evaluations should give preference to alternatives that degrade source water the least during use. Evaluators shall compare alternatives according to the difference in water quality between the total water input (direct and indirect) from the source and the water output (direct and indirect) after use. A smaller differential implies that less treatment is needed to improve lower quality water after use and before that water is returned to either the original source or generally released into the environment. The probability of increased energy consumption increases as the variance between source and output water quality increases.

Water degradation (WD_x) is calculated by first identifying all the potential uses of water that an alternative requires during its life cycle. When data are available, evaluators should record the volume of water required by the system or component (V_x) per type of use (i).

Evaluators should then assess the water quality requirements needed for each type of use according to the water quality categories presented in Table 8. There are 11 water quality categories described in Table 8 that are ranked from highest quality to lowest quality. Using these water category designations, evaluators should assign a designation letter to both the quality of the input water, which is represented by the horizontal axis in Figure 8, and the required quality of the output water, which is represented by the vertical axis in Figure 8. Evaluators should then plot the water use for each alternative on Figure 8. Evaluators should note that an alternative may use different sources of water and should provide a separate plot for each source used by each alternative.

The water degradation score (WDs_x) for a single plot (i.e., single type of use for a given alternative) is determined by the score designated in Figure 8 to the gradient plane in which that plot falls within. A score of 0 means that the input water quality and the output water quality for a given type of use (n) are perfectly matched, implying that this particular type of use does not degrade the water. A score of 10 means that the input and output water quality vary drastically for a given type of use (n), implying that the water has be severely degraded and intensive water treatment or specially water handling will be required. A score of 10 is the worst possible score an alternative can earn.

Once the water degradation score is recorded for use type for a given alternative, evaluators should translate those scores into a weighted average by multiplying $WDs_x$by the percentage of total water used by that system or component that V_x comprises (see Equation 21 and Figure 6).[9]

$$(21)\quad WD_x = \sum_{i=1}^{n} \frac{V_i}{(A+B+C)} \times WDs_x = \sum_{i=1}^{n} \frac{V_i}{(C+D+E+F)} \times WDs_x$$

[9] Total water used is the sum of total direct water ($A_1 + B_1 + C_1$ or $C_1 + D_1 + E_1 + F_1$) and total indirect water ($A_2 + B_2 + C_2$ or $C_2 + D_2 + E_2 + F_2$), see Figure 6.

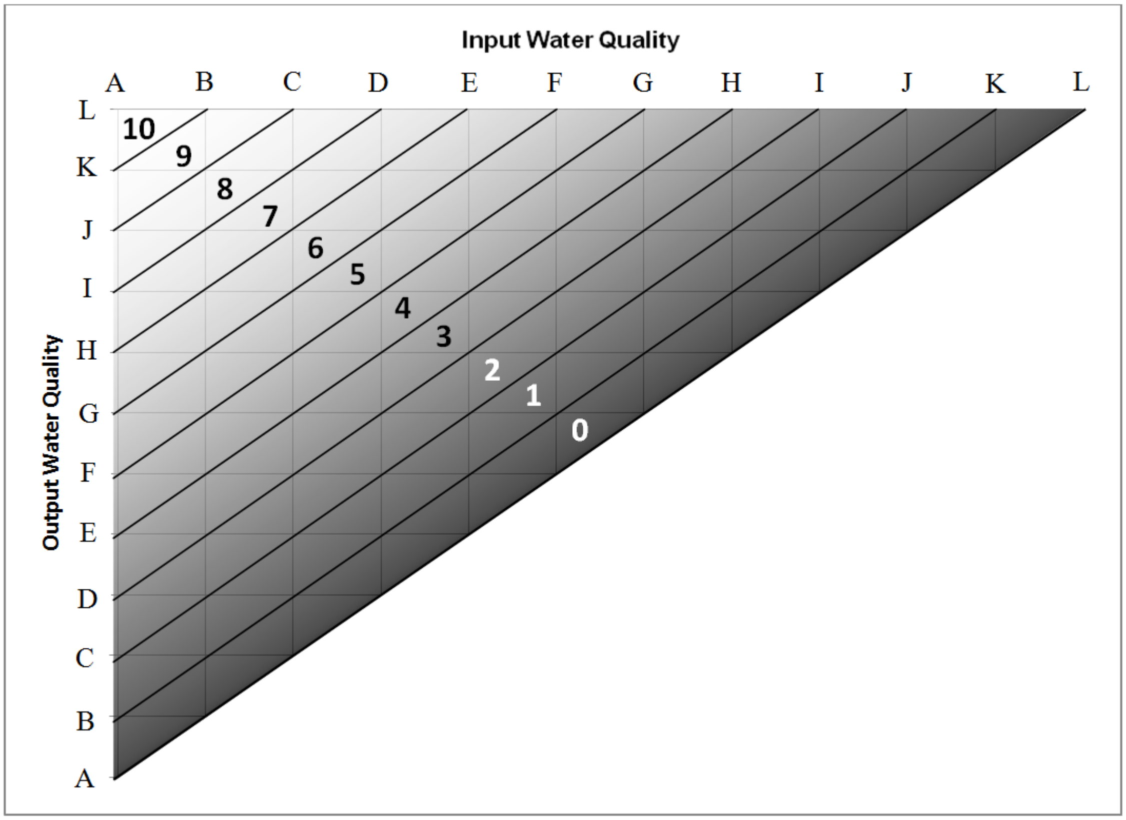

FIGURE 8. Water degradation scoring diagram

6.5.2.22 Water Scarcity. The goal of this impact category is ensure that evaluators consider the scarcity of the water source in all regions where an alternative will consume water and give preference to alternatives that use water in less scarce water regions of the world. Evaluators should assess alternatives according to the water scarcity of the region where water used directly by the system or component occurs. Water scarcity occurs when the amount of water needed from lakes, rivers or groundwater exceeds the amount of water available, compromising the ability of water sources to adequately satisfy all mission-related, societal and ecosystem requirements.

Water scarcity should be calculated for the region(s) where alternatives are expected to be utilized, maintained, or based. When evaluating mobile alternatives, such as deployable equipment, evaluators should restrict the assessment of water scarcity to regions where the system or component is home based or maintained at the depot level. Each alternative will receive a calculated water scarcity metric (WS_x) according to Equation 22. Evaluators should use Table 9 to identify a water scarcity index that is most applicable to the alternatives being evaluated and to calculate the water scarcity indicator (WSI_i) for each alternative using that same methodology across all alternatives. If, during its life span, an alternative is used in multiple water regions, with varying levels of water scarcity, a water scarcity indicator should be calculated for each applicable region (i). A weighted averaged of the water scarcity indicators should then be calculated according to the proportion of water withdrawn per region (VW_i) in relation to sum of direct and indirect water use (see Figure 6).[10]

$$(22) \quad WS_x = \sum_{i=1}^{n} \frac{VW_i}{(A+B+C)} \times WDI_x = \sum_{i=1}^{n} \frac{VW_i}{(C+D+E+F)} \times WDI_x$$

TABLE 9. Water scarcity indexes, definitions, and calculations

Title	Definition	Input Data Needed	Calculation
Water Stress Index	Amount of water resource oversubscription for a defined area	Domestic (W_D), industrial (W_i), and agricultural water (W_a) withdrawals; available water supply (Q_T)	$\frac{\sum W_D + W_i + W_a}{Q_T}$ High degree of oversubscription is indicated when $\sum W_D + W_i + W_a$ is more than 40% of Q_T
Water Supply Stress Index Model (WaSSI)	Measures watershed stress by comparing water supply and demand for a specific area	Location (zipcode), dates, climate scenario; past demand is estimated from U.S. Geological Survey (USGS) or State data; future projections in land-use, land-management population, and climate change	WaSSI model (available at http://www.fs.fed.us/ccrc/tools/wassi.shtml) outputs water supply and demand for particular timeframe. A ratio is provided comparing demand to supply. A low ratio (<<1) indicates less water stress, whereas a ration approaching or exceeding 1 represents much higher watershed stress.
Falkenmark Water Stress Indicator	Comparison of annual available water supplies to standardized per capita water use	Population, water use patterns, annual available renewable water supplies	Compare to scale: **Water available per capita per year** – **Interpretation** < 500 m^3 – Below manageable capability; absolute scarcity 500 – 1000 m^3 – Chronic scarcity 1000 -1600 m^3 – Periodic or limited water shortages can be expected >1600 m^3 – Adequate water supply
Global Water Risk	Geographic Information	Domestic, agricultural, and	Model and mapping tools available at http://www.water-risk-

[10] Total water used is the sum of total direct water ($A_1 + B_1 + C_1$ or $C_1 + D_1 + E_1 + F_1$) and total indirect water ($A_2 + B_2 + C_2$ or $C_2 + D_2 + E_2 + F_2$), see Figure 6.

Title	Definition	Input Data Needed	Calculation
Index (GWRI)	System (GIS) overlays of hydrologic, climatalogic, economic, demographic, planning, and business info per land area	industrial water demand based on population density, urban and rural location, local water use data (metering), agricultural and industrial activities	index.com/methodology.html
Water Scarcity Index	Index related to recommended use of 40% compared to available water supply. Scarcity may be due to physical reasons, climate, or socio-economic factors	Water use information and local water availability	$\left[\left(\frac{Total\ Freshwater\ Withdrawals}{Total\ Renewable\ Water\ Available}\right) - 0.4\right] \times \left[\frac{Freshwater\ Withdrawals}{Total\ Water\ Use}\right]$

6.5.2.23 <u>Land Degradation.</u> The goal of this impact category is to ensure that evaluators consider any land degradation resulting from the life cycle activities of the alternative being evaluated and give preference to alternatives that minimize ecosystem degradation associated with the incremental land use needed to support the alternative. Evaluators should compare alternatives based on the type of land degradation that would occur on incremental land used to support activities associated with testing, evaluation, basing or sustaining the system or component. Degradation should be measured as the type of land transformation that will occur as a result of developing each alternative. When evaluating land transformation, evaluators should consider the existing land that would be incrementally transformed. Consideration of the existing state of the land is important because different types of land transformation (e.g., forest to runway) lead to different degrees of impact. For example, converting highly productive land, such as forests, to a built environment has a greater impact than converting less productive land, such as deserts. Such impact should be assessed by estimating the restoration time of that plot of land.

Evaluators also should compare alternatives according to the amount of time for which the incrementally transformed plot of land will be occupied to meet the system's or component's spatial requirements. Occupation of transformed land delays restoration to the pre-conversion state. (Example: If the restoration time for a converted forest is 200 years, and the expected occupation is 50 years, the actual restoration would not occur until after 250 years).

Within this metric, alternatives that result in land transformations with the lowest combined restoration and occupation times should be considered superior, and thus, should be preferred over other alternatives.

To calculate a land degradation score (LDS_x), evaluators should first calculate the weighted average restoration time ($WART_x$) for the incremental land use by dividing each incremental plot of land (i) into ecosystem designations that meet the descriptions detailed in Table 1. When dividing the incremental plot of land into ecosystem designations, evaluators shall also record the amount of land, in acres, that would be consumed under each ecosystem designation. To calculate $WART_x$, evaluators shall then multiply the total amount of land within each ecosystem designation (ED_x) by each designation's respective restoration (RT_x) time detailed in Table 1. Evaluators should then sum those results for each ecosystem designation applicable to each alternative. Equation 23 summarizes how $WART_x$ should be calculated. This calculation should be made in terms of the functional unit (see 6.1).

$$(23) \quad WART_x = \sum_{i=1}^{n} ED_x \times RT_x$$

Evaluators should then calculate a weighted average occupation time ($WAOT_x$) that would result from any incremental land use activities. In doing so, evaluators should record each alternative's expected occupation time, in years, on the incremental land used to support the activities of that system or component. If separate ecosystem designated plots of land (ED_x) have different expected occupation times (OT_x), evaluators should calculate the weighted average for occupation time, using the percentage of total incremental land (ILU_x) that each plot represents as the weights (see Equation 24). This calculation shall be made in terms of the functional unit (see 6.1).

$$(24) \quad WAOT_x = \sum_{i=1}^{n} \left(\frac{ED_x}{ILU_x}\right) \times OT_x$$

To calculate each alternative's land degradation score (LDS_x), evaluators should sum the weighted average restoration time ($WART_x$) and the weighted average occupation time ($WAOT_x$). Equation 25 summarizes this calculation. This score represents the estimated average time that it would take for the incremental land used by a given alternative to be restored to its original state.

$$(25) \quad LDS_x = WART_x \times WAOT_x$$

TABLE 10. Common ecosystem designations and restoration times

		Existing Land Type						
Land Type After Transformation	(Years)	Agri_hi	Agri_li	Artificial_hi	Artificial_li	Forest_hi	Forest_li	Non-use
	Agri_hi	0	10	0.5	2	25	50	500
	Agri_li	0.5	0	0.5	2	25	50	500
	Artificial_hi	5	10	0	2	25	50	500
	Artificial_li	2	5	0.5	0	25	50	500
	Forest_hi	1	2	0.5	2	0	25	0
	Forest_li	1	2	0.5	2	10	0	0
	Non-use	0.5	0.5	0.5	2	10	25	0

Systems that consume and transform the least amount of land (i.e., have a smaller incremental land footprint) are considered superior, and thus, should be preferred over other alternatives.

6.6 <u>How to Compare Alternatives Once the Impacts Are Assessed.</u> Evaluators shall utilize the scoring methodology in 6.5 to compare alternatives. When determining the most sustainable alternative (i.e., comparing across impact categories), evaluators shall use those resulting scores as inputs for analyses conducted in this section.

6.6.1 <u>Spider Web Diagram (also called radar chart).</u> The spider web diagram provides a visual means of comparing alternatives based on their sustainability impacts. Each "spoke" of the spider web diagram represents one of the 23 impact categories. Impact category results of each alternative are plotted on the spider web diagram. Systems with the largest impact are represented by lines on the outside perimeter of the spider web diagram. Systems with the smallest impact are represented by lines closest to the center of the spider web diagram. In many cases, systems will have small impacts for some impact categories, but large impacts for others resulting in an asymmetrical plot on the spider web diagram. Evaluators should use the spider web diagram to discern tradeoffs in impact categories for a single system as well as tradeoffs among multiple systems, all of which is visualized by the spider web diagram.

Prior to plotting results on the spider web diagram, evaluators should note that impact category results generated from using scoring factors are incomparable from an absolute perspective; making it difficult to compare results across both alternatives and impact categories. To alleviate this common challenge, it is recommended that evaluators index SLCA results so that alternatives can be compared across impact categories. The SLCA tool referenced in 6.5.1 automatically calculates SLCA results, indexes the results, and generates the spider web diagram making for evaluators to use. However, if evaluators choose to conduct the assessment manually, guidance is provided below on how to index the SLCA results and generate a spider web diagram.

The results of the impact assessment under the guidance of 6.5 can be used to assign indexed scores (IS_X) to each alternative within a particular impact category by calculating each alternative's impact in terms of percentage of the worst performer. According to this indexing methodology, the worst performer will be assigned an indexed score of 100% and represents the outermost parameter of the scale against which all other alternatives will be assessed. IS_X for all alternatives not considered worst is thus calculated as the difference between the worst performing score (A_{worst}) and Alternative X's score (A_X), subtracted from one and divided by the worst performer's score (see Equation 26). This value is then converted into a percentage by multiplying by 100.

$$(26) \quad IS_x = \left[\frac{1-(A_{worst}-A_x)}{A_{worst}}\right] \times 100$$

It is important to note that when comparing alternatives, the larger the impact, the worse the alternative. This implies that alternatives with relatively smaller impact footprints (smaller indexed scores) are considered more sustainable.

6.6.2 Comparing Alternatives. Once an indexed score is assigned to each alternative within each impact category, evaluators can then use these unit-less scores to compare alternatives across sub-attributes. When comparing alternatives across sub-attributes, evaluators can use one of the following two methodologies:

a. Weighted Indexed Score. Evaluators may calculate a weighted indexed score (WIS_X) for each alternative if, and only if, the following conditions are met:

   i. Evaluators are able to assemble key stakeholders, decision makers and subject matter experts (SMEs); and

   ii. Those key stakeholders, decision makers and SMEs reach consensus on acceptable weights for measuring the overall importance of each impact category i (W_i).

   Equation 27 can be used to calculate the WIS_x for a given alternative across all impact scores (SAS_i). Under this methodology, the lowest score would indicate the smallest impact footprint and would be considered to be the most sustainable alternative.

   It is important to note that assembling all relevant stakeholders, decision makers and subject matter experts can be difficult and time and resource intensive. Furthermore, once assembling this group, it is often very difficult for such a group to reach consensus on appropriate scoring weights. This method should not be used if the above criteria cannot be satisfied.

$$(27) \quad WIS_x = \sum_{i=1}^{n}(W_i \times SAS_i)$$

b. Spider Web Diagram Reduction. Evaluators can also present the indexed scores in a spider web diagram (see Figure 9) with a scale of 0% to 100%. Once all alternatives are graphed on a spider web diagram, evaluators should reduce the number of acceptable alternatives by eliminating those that have the largest impact footprint. In Figure 9, it is very apparent that Alternative 1 has the smallest footprint, and is thus the most sustainable materiel solution. However, most scenarios will not be as obvious and will require tradeoffs across sub-attributes. Evaluators should determine, and provide justification for, the methodology for making such trades and eliminating alternatives.

Evaluators should note that using the spider web diagram reduction methodology is less subjective than using weighted indexed scores and does not rely on a group consensus to eliminate alternatives with larger impact footprints. However, this method is still subjective in that decision makers must still decide on which impact categories should take priority when tradeoffs are needed.

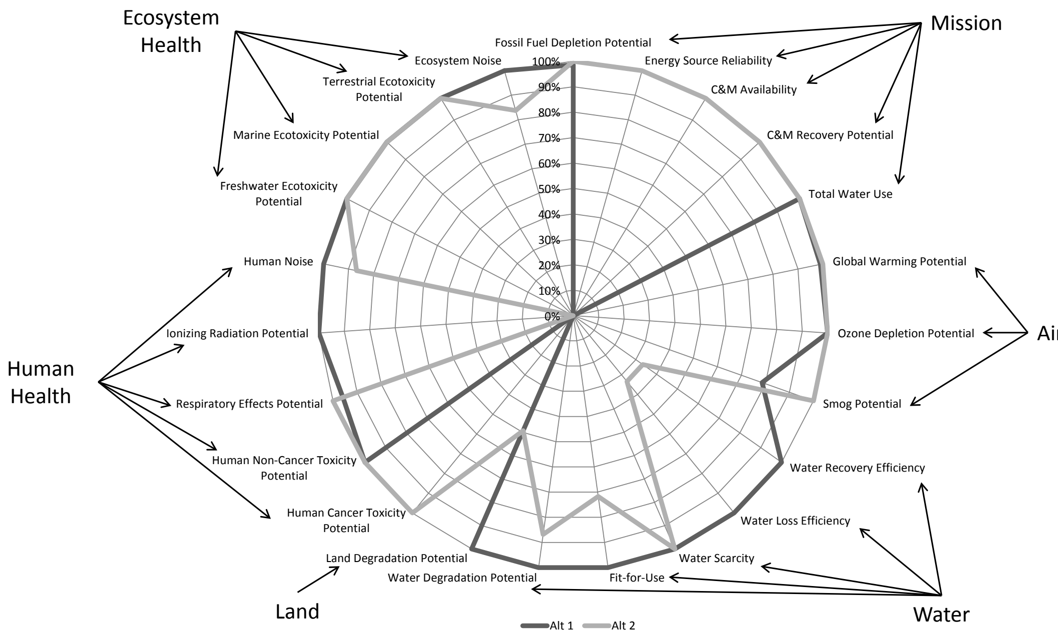

FIGURE 9. Example spider web chart

6.6.3 Trade Space Analysis. Evaluators should use results from the weighted indexed score or spider web diagram to identify the most sustainable materiel solution. This requires evaluating the tradeoffs between alternatives in human health and environmental impacts as well as cost, schedule, and performance. The weighted indexed score or spider web diagram helps to comprehend and justify tradeoffs by enabling a robust comparison of human health and environmental impacts between alternatives.

6.6.4 Detailed Design. Evaluators should use results from the weighted indexed score or spider web diagram to inform detailed design of systems. Results can be generated for different design options enabling evaluators to compare the human health and design impacts of design choices. Furthermore, by analyzing the resource requirements identified while building an input inventory with resulting human health and environmental impacts, evaluators can identify resource requirements that are driving the most significant impacts. This information can be used to inform design.

7. DOCUMENTING SLCA PROCESS

The data inputs, methods, results, and assumptions of the SLCA should be documented in an adequate form to ensure transparency. Documentation should include, but is not limited to the following facets of the SLCA: 1) reasons for carrying out the SLCA; 2) system boundaries including omissions of life cycle stages; 3) scope of the study including function and performance characteristics of alternative systems and functional unit; 4) types of inputs and outputs of the system and assumptions or data limitations; 5) decisions about data including data sources, data quality, and assumptions or limitations; 6) choice of impact categories including a description of any new impact categories or omitted impact categories; and 7) name and affiliation of evaluators and the date of assessment.

APPENDIX A. DETAILED EXPLANATION OF ACTIVITY DECRIPTORS

Active and Stationary Systems. An active and stationary system or component is one that does not move on its own accord and actively consumes resources during its operation to properly achieve its function. Active and stationary systems or components affect the input inventory accordingly:

a. Energy: Active and stationary systems or components typically consume some form of energy during operation. The energy-use profile for active and stationary systems or components is typically dominated by the O&S phase of the life cycle; both in terms of the direct energy needed to operate the system or component and the indirect energy needed to supply that system or component with adequate amounts of energy.

b. Water: Active and stationary systems or components typically consume water for operation, cleaning or maintenance purposes. The water-use profile for active and stationary systems or components is typically, although not always, dominated by the O&S phase; both in terms of the direct water needed to operate the system or component and the indirect water needed to supply that system or component with adequate amounts of water. However, it is important to note that the water-use profile for some active systems that do not require the use of water during operation, cleaning or maintenance is typically dominated by the manufacturing phase of the life cycle.

c. Chemicals and Materials: Active and stationary systems or components typically consume the largest inventory (i.e., number) of chemicals and materials and largest amount (i.e., quantity) of those chemicals and materials during the manufacturing phase. It is important to note that for these types of systems and components, the O&S phase typically represents a greater proportion of life cycle chemical and material impact than the O&S phase for passive (either mobile or stationary) systems and components because of heavier use requirements, which typically lead to greater maintenance activities (i.e., chemical and material use for repair and replacement activities). Systems and components that are active and stationary differ from those that are active and mobile in that the O&S phase typically represents a lower impact because the lack of mobility of those systems usually results in fewer replacement and repair activities. Although the chemical-and-material-use profile for active and stationary systems and components is typically dominated by the manufacturing phase, the O&S phase could dominate when the resulting use for a given system or component is compounded due to a long system or component lifespan or a high frequency of O&S activities (e.g., cleaning, maintenance, operations) and cause such use to outweigh the contribution from the manufacturing phase. This scenario is not as common in stationary systems as it is for mobile systems.

d. Land: Like all systems and components, regardless of their activity descriptors, the incremental land use caused by active and stationary systems and components is typically greatest during the manufacturing phase. Any increase in a manufacturing footprint (e.g., new manufacturing facility or expanded manufacturing line) needed to manufacture a system or component that causes an incremental increase in the use of previously undeveloped land should be directly tied to that system or component. In terms of O&S, any incremental facilities or other developed land needed to store or support the system or component also should be tied to that system or component. It is important to note that, unlike for mobile systems and components, the incremental land requirements in the O&S phase for stationary systems and components is typically minor compared to the manufacturing phase.

Active and Mobile. An active and mobile system or component is one that can move on its own accord and actively consumes resources during its operation to properly achieve its function. Active and mobile systems or components affect the input inventory accordingly:

a. Energy: Active and mobile systems or components typically consume some form of energy during operation, which includes self-employed mobility. The energy-use profile for active and mobile systems or components is typically dominated by the O&S phase of the life cycle; both in terms of the direct energy needed to operate the system or component and the indirect energy needed to supply that system or component with adequate amounts of energy.

b. Water: Active and mobile systems or components typically consume water for operation, cleaning or maintenance purposes. The water-use profile for active and mobile systems or components is typically, although not always, dominated by the O&S phase; both in terms of the direct water needed to operate the system or component and the indirect water needed to supply that system or component with adequate amounts of water. However, it is important to note that the water-use profile for some active systems that do not require the use of water during operation, cleaning or maintenance is typically dominated by the manufacturing phase of the life cycle.

c. Chemicals and Materials: Active and mobile systems or components typically consume the largest inventory (i.e. number) of chemicals and materials and largest amount (i.e. quantity) of those chemicals and materials during the manufacturing phase. It is important to note that for these types of systems and components, the O&S phase typically represents a greater proportion of life cycle chemical and material impact than the O&S phase for passive (either mobile or stationary) systems and components because of heavier use requirements, which typically lead to greater maintenance activities (i.e., chemical and material use for repair and replacement activities). Although the chemical-and-material-use profile for active and mobile systems and components is typically dominated by the manufacturing phase, the O&S phase could dominate when the resulting use for a given system or component is compounded due to a long system or component lifespan or a high frequency of O&S activities (e.g., cleaning, maintenance, operations, etc.) and cause such use to outweigh the contributions from the manufacturing phase.

d. Land: Like all systems and components, regardless of their activity descriptors, the incremental land use caused by active and mobile systems and components is typically greatest during the manufacturing and O&S phases. In terms of manufacturing, any increase in a manufacturing footprint (e.g., new manufacturing facility or expanded manufacturing line) needed to manufacture a system or component that causes an incremental increase in the use of previously undeveloped land should be directly tied to that system or component. In terms of O&S, any incremental facilities or other developed land needed to operate, store, or support the system or component also should be tied to that system or component. It is important to note that mobile systems and components typically have a larger land impact, in terms of proportion of impact throughout the system or component life cycle, than stationary systems or components. The mobile nature of these systems and components typically requires the use of more land because O&S activities can occur in multiple locations (e.g., runways, depots, ports, etc.). It is also important to note that the end-of-life land requirements needed for mobile systems can also be large due to greater waste streams caused by sometimes intensive maintenance (e.g., repair and replacement) activities.

Passive and Stationary. Passive and Stationary: A passive and stationary system or component is one that does not move on its own accord and does not consume resources during its operation. Being stationary, these systems and components do not utilize support systems for mobility to properly achieve their function. Passive and stationary systems or components affect the input inventory accordingly:

a. Energy: The energy-use profile for passive and stationary systems or components is typically dominated by the manufacturing phase of the life cycle because these systems and components do not consume energy during operation.

b. Water: The water-use profile for passive and stationary systems or components is typically dominated by the manufacturing phase of the life cycle because these systems and components typically do not consume much water for O&S activities. If water is consumed during O&S, it is typically for cleaning and maintaining such systems and components due to exposure to harsh environmental conditions. It is important to note that passive and stationary systems that have a long lifespan and are frequently cleaned and maintained could consume a proportionally large amount of water in the O&S phase relative to other life cycle phases.

c. Chemicals and Materials: Passive and stationary systems or components typically consume the largest inventory (i.e. number) of chemicals and materials and largest amount (i.e. quantity) of those chemicals and materials during the manufacturing phase. It is important to note that for these types of systems and components, the O&S phase typically represents a smaller proportion of life cycle chemical and material impact than the O&S phase for active (either mobile or stationary) systems and components because of less extreme use requirements, which typically lead to less maintenance activities (i.e., chemical and material repair and replacement). If chemicals or materials are consumed during O&S, it is typically for cleaning and maintaining such systems and components due to exposure to harsh environmental conditions. It is important to note that passive and stationary systems that have a long lifespan and are frequently cleaned and maintained could consume a proportionally large amount of chemicals and materials in the O&S phase relative to other life cycle phases.

d. Land: Like all systems and components, regardless of their activity descriptors, the incremental land use caused by passive and stationary systems and components is typically greatest during the manufacturing phase. Any increase in a manufacturing footprint (e.g., new manufacturing facility or expanded manufacturing line) needed to manufacture a system or component that causes an incremental increase in the use of previously undeveloped land should be directly tied to that system or component. In terms of O&S, any incremental facilities or other developed land needed to store or support the system or component also should be tied to that system or component. It is important to note that, unlike for mobile systems and components, the incremental land requirements in the O&S phase for stationary systems and components is typically minor compared to the manufacturing phase.

e. Hazards Management: Like all systems and components, regardless of their activity descriptors, there is no general guidance for which life cycle phases, or the activities occurring within a given phase, contribute to the largest human health or environmental impact caused by exposure to chemical, biological, or physical hazards including noise, radiation, and ergonomics. However, active systems typically generate the potential for exposures to these hazards during manufacturing and O&S phases.

Passive and Mobile. A passive and mobile system or component is one that is mobilized using support systems (i.e., does not move on its own accord) and does not consume resources during its operation to properly achieve its function. Passive and mobile systems or components affect the input inventory accordingly:

a. Energy: The energy-use profile for passive and mobile systems or components is typically dominated by the manufacturing phase of the life cycle because these systems and components do not consume energy during operation. It is important to note that passive and mobile systems that are frequently transported by support systems could have a high energy impact in the O&S phase if the amount of indirect energy use for that transport is high.

b. Water: The water-use profile for passive and mobile systems or components is typically dominated by the manufacturing phase of the life cycle because these systems and components typically do not consume much water for O&S activities. If water is consumed during O&S, it is typically for cleaning and maintaining such systems and components due to transport or exposure to harsh environmental conditions. It is important to note that passive and mobile systems that have a long lifespan and are frequently cleaned and maintained could consume a proportionally large amount of water in the O&S phase relative to other life cycle phases.

c. Chemicals and Materials: Passive and mobile systems or components typically consume the largest inventory (i.e. number) of chemicals and materials and largest amount (i.e. quantity) of those chemicals and materials during the manufacturing phase. It is important to note that for these types of systems and components, the O&S phase typically represents a smaller proportion of life cycle chemical and material impact than the O&S phase for active (either mobile or stationary) systems and components because of less extreme use requirements, which typically lead to less maintenance activities (i.e., chemical and material repair and replacement). If chemicals or materials are consumed during O&S, it is typically for cleaning and maintaining such systems and components due to transport or exposure to harsh environmental conditions. It is important to note that passive and mobile systems that have a long lifespan and are frequently cleaned and maintained could consume a proportionally large amount of chemicals and materials in the O&S phase relative to other life cycle phases.

d. Land: Like all systems and components, regardless of their activity descriptors, the incremental land use caused by passive and mobile systems and components is typically greatest during the manufacturing and O&S phases. In terms of manufacturing, any increase in a manufacturing footprint (e.g., new manufacturing facility or expanded manufacturing line) needed to manufacture a system or component that causes an incremental increase in the use of previously undeveloped land should be directly tied to that system or component. In terms of O&S, any incremental facilities or other developed land needed to operate, store, or support the system or component also should be tied to that system or component. It is important to note that mobile systems and components typically have a larger land impact, in terms of proportion of impact throughout the system or component life cycle, than stationary systems or components. The mobile nature of these systems and components typically requires the use of more land because O&S activities can occur in multiple locations (e.g., runways, depots, ports, etc.). It is also important to note that the end-of-life land requirements needed for mobile systems can also be large due to greater waste streams caused by sometimes intensive maintenance (e.g., repair and replacement) activities.

APPENDIX B. EXAMPLE LIFE CYCLE ACTIVITY PROFILE
(GENERIC AIRCRAFT)

Attribute	Life Cycle Phases			
	Raw Materials Acquisition	***Production & Deployment***	***Operations & Sustainment (O&S)***	***End of life***
Energy	• Mining of minerals & fuel • Refining of Fuel	• Material fabrication and assembly • Flight testing	• Fuel use (direct) • Transportation of fuel to FOB or depot (indirect) • Transportation of water to FOB or depot (indirect)	• Reconditioning of engines for reuse • Recycling of aluminum frame, scraps & electronics
Water	• Mining of minerals & fuel • Refining of Fuel	• Coatings	• Paint stripping (direct) • Engine and airframe cleaning (direct)	• N/A
Chemicals & Materials	• N/A	• Coatings & other solvents	• Resurfacing • Fuel use	• Reconditioning of engines for reuse • Recycling of aluminum frame, scraps & electronics
Land Use	• Mining of minerals & fuel • Refining of Fuel	• Incremental footprint for manufacturing facility	• Two additional runways needed • New hangar needed for fleet	• Additional landfill acreage needed for solid waste

APPENDIX C. SLCA SCORING FACTORS FOR ALL RESOURCE INPUTS

SLCA Scoring Factors
for All Inputs.xlsx

APPENDIX D. CHARACTERIZATION FACTORS

Impact Category	References
Fossil Fuel Depletion Potential	Fossil Fuel Depletion Potential characterization factors are from Section 13 of Goedkoop, M., R. Heijungs, M. Huijbregts, A. De Schryver, J. Struijs, and R. van Zelm. ReCiPe 2008: a life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level, First Edition. PRé Consultants, Amersfoort, Netherlands, 2009.
Energy Source Reliability	Energy Source Reliability is a score calculated by the user for each specific type of energy carrier. These scores are determined in the "Input - Energy" tab. No characterization factors are needed for converting inputs to impact potential.
Chemical and Material Availability	Chemical and Material Availability is a score calculated by the user for each chemical or material input. These scores are determined in the "Input - C&M" tab. No characterization factors are needed for converting inputs to impact potential.
Chemical and Material Recovery Potential	Chemical and Material Recovery Potential is a score calculated by the user for each chemical or material input. These scores are determined in the "Input - C&M" tab. No characterization factors are needed for converting inputs to impact potential.
Total Water Use	Total Water Use is a score calculated by the user in accordance with the amount of water consumed. These scores are determined in the "Input - Water" tab. No characterization factors are needed for converting inputs to impact potential.
Global Warming Potential	Global Warming Potential characterization factors are from the U.S. Environmental Protection Agency's Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI). Information on TRACI is available from http://www.epa.gov/nrmrl/std/traci/traci.html
Ozone Depletion Potential	Ozone Depletion Potential characterization factors are from the U.S. Environmental Protection Agency's Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI). Information on TRACI is available from http://www.epa.gov/nrmrl/std/traci/traci.html
Smog Potential	Smog Potential characterization factors are from the U.S. Environmental Protection Agency's Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI). Information on TRACI is available from http://www.epa.gov/nrmrl/std/traci/traci.html
Water Recovery Efficiency	Water Recovery Efficiency is a score calculated by the user in accordance with the type and amount of water consumed. These scores are determined in the "Input - Water" tab. No characterization factors are needed for converting inputs to impact potential.
Water Loss Efficiency	Water Loss Efficiency is a score calculated by the user in accordance with the type and amount of water consumed. These scores are determined in the "Input - Water" tab. No characterization factors are needed for converting inputs to impact potential.
Water Scarcity	Water Scarcity is a score calculated by the user using a chosen indexing framework for all water consumed in regions with scarce water resources. These scores are determined in the "Input - Water" tab. No characterization factors are needed for converting inputs to impact potential.
Fit-for-Use	Fit-for-Use is a score calculated by the user in accordance with the type and amount of water consumed. These scores are determined in the "Input - Water" tab. No characterization factors are needed for converting inputs to impact potential.
Water Degradation Potential	Water Degradation Potential is a score calculated by the user in accordance with the type and amount of water consumed. These scores are determined in the "Input - Water" tab. No characterization factors are needed for converting inputs to impact potential.
Land Degradation Potential	Land Degradation Potential comprises ecosystem designations and occupation time factors as defined by Koellner, T. and R.W. Scholz. 2007. Assessment of land use impacts on the natural environment. Part 1: an analytical framework for pure land occupation and land use change. Int Journal of Life Cycle Assess. 12(1):16-23.

Impact Category	References
Human Cancer Toxicity Potential	Human Cancer Toxicity Potential characterization factors are from the USEtox^{TM} model. For human health characterization, characterization factors for air were averaged across urban and continental releases, calculated based on 50% urban and 50% continental air to assess unspecified emissions to these compartments. This model is an environmental model for the characterization of human and ecotoxicological impacts in life cycle-based assessments. It has been developed by a team of researchers from the Task Force on Toxic Impacts under the UNEP-SETAC Life Cycle Initiative. The USEtox^{TM} model and the characterization factors are used to assess toxicity in comparative assessments. The characterization factors listed here include interim and recommended data. Updated versions of the USEtox^{TM} characterization factors are available from http://www.usetox.org/. For more information about the USEtox^{TM} model, see Rosenbaum, R.K. et al. 2008. USEtox - the UNEP-SETAC toxicity model: recommended characterization factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment. Int J Life Cycle Assess. 13:532-546.
Human Non-Cancer Toxicity Potential	Human Non-Cancer Toxicity Potential characterization factors are from the USEtox^{TM} model. For human health characterization, characterization factors for air were averaged across urban and continental releases, calculated based on 50% urban and 50% continental air to assess unspecified emissions to these compartments. This model is an environmental model for the characterization of human and ecotoxicological impacts in life cycle-based assessments. It has been developed by a team of researchers from the Task Force on Toxic Impacts under the UNEP-SETAC Life Cycle Initiative. The USEtox^{TM} model and the characterization factors are used to assess toxicity in comparative assessments. The characterization factors listed here include interim and recommended data. Updated versions of the USEtox^{TM} characterization factors are available from http://www.usetox.org/. For more information about the USEtox^{TM} model, see Rosenbaum, R.K. et al. 2008. USEtox - the UNEP-SETAC toxicity model: recommended characterization factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment. Int J Life Cycle Assess. 13:532-546.
Respiratory Effects Potential	Respiratory Effects Potential characterization factors are from the U.S. Environmental Protection Agency's Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI). Information on TRACI is available from http://www.epa.gov/nrmrl/std/traci/traci.html
Ionizing Radiation Potential	The Ionizing Radiation Potential characterization factor is employed when uranium is used as a fuel for energy, it is a binary characterization factor. If uranium is used as fuel, the number of BTUs associated with that fuel is multiplied by one. and all other fuels receive a score of zero.
Freshwater Ecotoxicity	Freshwater Ecotoxicity characterization factors are from the USEtox^{TM} model. For freshwater ecotoxicological characterization, characterization factors for air were averaged across urban and continental releases, calculated based on 50% urban and 50% continental air to assess unspecified emissions to these compartments. This model is an environmental model for the characterization of human and ecotoxicological impacts in life cycle-based assessments. It has been developed by a team of researchers from the Task Force on Toxic Impacts under the UNEP-SETAC Life Cycle Initiative. The USEtoxTM model and the characterization factors are used to assess toxicity in comparative assessments. The characterization factors listed here include interim and recommended data. Updated versions of the USEtoxTM characterization factors are available from http://www.usetox.org/. For more information about the USEtoxTM model, see Rosenbaum, R.K. et al. 2008. USEtox - the UNEP-SETAC toxicity model: recommended characterization factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment. Int J Life Cycle Assess. 13:532-546.
Marine Ecotoxicity	Marine Ecotoxicity characterization factors were drawn from Section 7 of Goedkoop, M., R. Heijungs, M. Huijbregts, A. De Schryver, J. Struijs, and R. van Zelm. ReCiPe 2008: a life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level, First Edition. PRé Consultants, Amersfoort, Netherlands,

Impact Category	References
	2009.
Terrestrial Ecotoxicity	Terrestrial Ecotoxicity characterization factors were drawn from Section 7 of Goedkoop, M., R. Heijungs, M. Huijbregts, A. De Schryver, J. Struijs, and R. van Zelm. ReCiPe 2008: a life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level, First Edition. PRé Consultants, Amersfoort, Netherlands, 2009.