FOREWORD

This provisional draft guidance, subject to final approval, can be used on a trial basis by all Departments and Agencies within the Department of Defense (DoD). The results of pilot tests are being incorporated and version 2.0 is planned for staffing, approval, and release in the first quarter of calendar year 2014.

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 and for the purposes of this document, sustainability is defined as 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 from now 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 can be inadvertently “pushed downstream” from acquisition program managers to the DoD operational, logistics, and installations management communities.

This guidance describes how a Sustainability Analysis, used in early conceptual and design decisions, can help design more sustainable systems (i.e., systems that 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 Analysis allows for more robust and informed trade space and supportability analyses. A Sustainability Analysis includes:

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. This document also references a spreadsheet tool that automates the calculations needed to compare alternatives for sustainability. The next version of this tool is expected to be web-based and more user-friendly. SLCA should be integrated into the overall Systems Engineering (SE) process, as described in the Defense Acquisition Guidance Chapter 4 on Systems Engineering.

2) Sustainability Life Cycle Costing, which gathers the life cycle costs related to the use of resources and their impacts on human health and the environment. A Sustainability Analysis 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. A future edition of this document will provide specific guidance on Sustainability Life Cycle Costing specifically tied to the current acquisition cost structure.

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 Analyses 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), Science & Technology Directorate, 4800 Mark Center Drive, Box 56, Suite 16G14, Alexandria, VA 22350 or e-mailed to paul.j.yaroschak.civ@mail.mil.
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1. SCOPE

1.1 Scope. The purpose of this document is to introduce the concept of Sustainability Analyses and provide detailed guidance on how to conduct a Streamlined Life Cycle Assessment (SLCA). Sustainability Analyses comprise a method called Life Cycle Assessment (LCA), which assesses human health and environmental impacts, and Life Cycle Costing\(^1\), which captures related life cycle costs of a system, product or process. 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\(^2\) 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 can be applied to new weapon system and platform acquisitions\(^3\) as well as legacy systems\(^4\) (see 3.2.19). 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 Analysis of Alternatives (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 guidance.

2.2 Government Documents.

2.2.1 Specifications, standards, and handbooks. The following specifications, standards, and handbooks form a part of this document to the extent specified herein.

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\(^1\) See DoD life cycle costing guidebooks such as DoD Product Support Business Case Analysis (BCA) Guidebook, DoD Product Support Manager Guidebook, and CAPE Operating & Support Cost Estimating Guide, DODI 5000.04M.
\(^2\) See ISO (the International Organization for Standardization) 14040 series on life cycle assessment (LCA).
\(^3\) 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.
2.2.2 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.

- CAPE Operating & Support Cost Estimating Guide
- Defense Acquisition Guidebook (available at https://dag.dau.mil/)
- Department of Defense Instruction 5000.02 (available at https://dag.dau.mil/)
- Department of Defense Instruction 5000.04M (available at https://dag.dau.mil/)
- Department of Defense Instruction 5200.44 (available at http://www.dtic.mil/dtic/)
- Department of Defense Product Support Business Case Analysis (BCA) Guidebook
- Department of Defense Product Support Manager Guidebook
- Department of Defense Strategic Sustainability Performance Plan (SSPP) (available at http://www.acq.osd.mil/ie/)
- Executive Order 13514 Federal Leadership in Environmental, Energy and Economic Performance

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

ILCD HDBK Analysis of existing Environmental Impact Assessment methodologies for use in Life Cycle Assessment

ILCD HDBK Framework and requirements for Life Cycle Impact Assessment models and indicators

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
ASSIST Acquisition Streamlining and Standardization Information System
CAPE Cost Assessment & Program Evaluation
BCA Business Case Analysis
C&M Chemical & Material
CCD Capability Development Document
CDR Critical Design Review
CFC Chlorofluorocarbons
CONOPS Concept of Operations
CTU Comparative Toxic Units
dBA Decibel A-weighting
DoD U.S. Department of Defense
E.O. Executive Order
EMP Engineering and Manufacturing Development
EPA U.S. Environmental Protection Agency
FRP Full-Rate Production
HCFC Hydrochlorofluorocarbon
HVAC Heating, Ventilation, and Air Conditioning
ICD Initial Capabilities Document
ISO International Organization for Standardization
LCA Life Cycle Assessment
LCI Life Cycle Inventory
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. For the purpose of defense acquisition, the following six areas of concern apply: mission, human health, ecosystem health, air, water and land.

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 used in the DoD SLCA methodology to convert an inventory input to an impact. Characterization factors are derived from widely accepted risk assessments, life cycle impact assessment methodologies, and scientific literature.

3.2.5 Chemical. A substance produced by or used in a chemical process.

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

3.2.7 Cost-effective. An alternative is cost-effective if it has a lower net life cycle cost than other alternatives after including all internal and external costs related to impacts.

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

3.2.10 Emission Factor. A measure of the average quantity of a specific pollutant or material discharged into a particular environmental medium (e.g., air, soil and water) by a specific process, fuel, equipment, or source. It is important to note that an emission factor provides a quantitative measure of the expected intensity of emissions associated with a specified activity. For example: kilograms of carbon dioxide emitted per gallon of diesel consumed by an internal combustion engine used to power a stationary generator.

3.2.11 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.

3.2.12 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 for 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.

3.2.13 Generalized emission factor. An emission factor (see 3.2.10) that is generalized for a particular input (e.g., diesel fuel, electricity) in that it does not represent a specified activity (i.e., combustion type) associated with that input. Thus, these factors are universally applied to the quantity of input for a specified input source across all possible activities that could be associated with that input (i.e., the “average” quantity of emission expected per quantity of input). For example: kilograms of carbon dioxide emitted per gallon of diesel consumed during an “average” combustion activity.

3.2.14 Hazardous chemical or material. Any item or substance that, due to its chemical, physical, toxicological, or biological nature, could cause harm to people, equipment, or the environment (see MIL-STD 882E) or for which a facility must maintain a safety data sheet.

3.2.15 Impact category. A standalone category representing a potential impact to one of the six areas of concern (see 3.2.2) resulting from a system’s LCI (see 3.2.21). Impact categories are defined by the impact resulting from the inputs and processes that occur as a result of the LCA, as quantified by an impact indicator (e.g., global warming, human toxicity) and its associated unit of measure (e.g., kg CO₂eq, CTUh).

3.2.16 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 (e.g., system use, basing, maintenance, system support infrastructure). The term incremental implies that this land would only be developed as a result of acquiring the new system.

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

3.2.18 **Indirect water.** The amount of water used to manufacture, sustain (e.g., maintain, transport, decommission) 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.

3.2.19 **Legacy system.** Legacy systems are considered systems already passed Milestone B, but may be undergoing notable modifications or revised operation and maintenance procedures.

3.2.20 **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, also referred to as process-level 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.

3.2.21 **Life cycle inventory (LCI).** A life cycle inventory involves creating an inventory of flows from and to the environment for weapon systems, platforms or equipment. Inventory flows include inputs of water, energy and raw materials, and releases to air, land and water.

3.2.22 **Marginal Cost of Consumption (MCC).** The cost an average US consumer—aggregated across industrial and commercial users—would incur to consume a single unit of energy (i.e., Btu) from a particular fossil fuel source. Non-fossil fuels have a MCC of zero. MCC, which is an adjusted average price paid per unit of energy, serves as a proxy for comparing the available supply of each type of fossil fuel (e.g., a relatively high MCC indicates a higher price paid per unit of energy, which implies that availability of that resource is relatively lower than other fossil fuels).

3.2.23 **Material.** Anything that serves as crude or raw matter to be used or developed.

3.2.24 **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 necessary to equip, operate, maintain and support military activities without disruption as to its application for administrative or combat purposes. In the case of a family of systems and system of systems approaches, an individual materiel solution may not fully satisfy a necessary capability gap on its own.

3.2.25 **Mission Critical.** Any function for which if compromised would degrade the system effectiveness in achieving the core mission for which it was designed. See Glossary, Part II, of DoDI 5200.44.
3.2.26 **Mission task (MT).** Any general task to be performed or effect to be achieved (e.g., hold targets at risk, provide countermeasures against surface-to-air missiles) derived directly from the capability requirements identified in the ICD or CDD. See 6.1.1 of the Air Force Analysis of Alternatives (AoA) Handbook: A Practical Guide to Analyses of Alternatives.

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

3.2.28 **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.

3.2.29 **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.

3.2.30 **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.

3.2.31 **Probability of disagreement.** The probability that conclusions reached by using the SLCA methodology in regard to human toxicity or ecotoxicity impact will be different from the conclusions reached when conducting a process-level LCA, as described by the ISO 14040 series of standards. In this context, the term “conclusion” refers to the determination that a particular alternative in a comparative assessment possesses a lower human toxicity or ecotoxicity impact than all other alternatives evaluated.

3.2.32 **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.

3.2.33 **Raw material acquisition.** A life cycle phase typically included within LCA, and sometimes SLCA. Raw material acquisition includes harvesting and processing natural resources from the environment.

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

3.2.35 **Renewable energy.** Energy from a source that can be replenished naturally within a relatively 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.

3.2.36 **Restoration time.** The duration, typically measured in years, required for a transformed plot of land to be naturally restored to its pre-transformed state.
3.2.37 **Reuse.** A chemical, material, or object that is used for another application, usually after refurbishing, once the lifespan of the original application is exhausted.

3.2.38 **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 indicator units.

3.2.39 **Sustainable acquisition.** Acquisition conducted in a manner that results in a system design and sustainment requirements that minimize impacts on mission, human health, and the environment over the lifecycle of the system, while meeting performance parameters.

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

3.2.41 **Sustainability Analysis.** Within the context of this document, a Sustainability Analysis comprises both a Life Cycle Assessment, which evaluates human health and environmental impacts, as well as a Life Cycle Costing, which captures life cycle costs of system, product, or process.

3.2.42 **Sustainable design.** The implementation of sustainable elements in new products, processes, or systems. These elements may include, but may not be limited to, 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.

3.2.43 **Sustainment.** Sustainment involves the supportability of fielded systems and their subsequent life cycle product support - from initial procurement to supply chain management (including maintenance) to reutilization and disposal. It includes sustainment functions such as initial provisioning, cataloging, inventory management and warehousing, and depot and field level maintenance.

3.2.44 **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.

3.2.45 **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 Analysis and should be consistent with the stated goal of the assessment.

3.2.46 **Water degradation.** When the water discharged after the completion of a specified activity—before any applicable water treatment activities have been initiated—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 has initiated numerous efforts to improve overall sustainability\(^5\) throughout its operations. Over the course of their life cycles, weapons systems and platforms use significant quantities of resources that can have major impacts on sustainability. The goal of this guidance is to help evaluators design the most sustainable systems that also satisfy performance requirements outlined in the Initial Capabilities Document (ICD) or the Capability Development Document (CCD).

4.1 Sustainability Analyses. Within the context of this document, a Sustainability Analysis comprises both a Streamlined Life Cycle Assessment (SLCA), which evaluates human health and environmental impacts, as well as a Life Cycle Costing, which captures life cycle costs of a system, product, or process (see FIGURE 1). A Sustainability Analysis 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. Sustainability Analyses provide an integrated management approach to measure and minimize the impacts of a product, system, or activity from cradle (i.e., raw material acquisition) to grave (i.e., end-of-life).

Sustainability Analyses 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 Analysis 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 air pollution but increase the impact to water scarcity. A Sustainability Analysis should capture these tradeoffs as well as capture the associated life cycle costs of various design choices. The SLCA

\[^5\] “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 Strategic Sustainability Performance Plan 2010.
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 Analyses 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 Analysis facilitates sustainable acquisitions by requiring data, information, and knowledge about a system and its life cycle early in the design process. Incorporating Sustainability Analyses into the acquisition process requires optimizing the trade space among performance, schedule, life cycle cost, and sustainability. Conducting Sustainability Analyses supports the Better Buying Power\(^6\) initiative and “designing for affordability” goal. Affordability not only includes the initial cost of delivering a system, but also the full life cycle costs, including those related to human health and environmental impacts.

4.2.1 Principles of Sustainable Design. The following is a list of general principles that guide sustainable design. Sustainability Analyses utilize methods (e.g., Activity Profile; Impact Assessment) that support sustainable design. Systems must be designed to meet performance requirements but can also be designed to be more sustainable than predecessor systems. When cost-effective over the entire life cycle, newly acquired systems should be designed to:

a. Utilize chemicals and materials that are: (1) non-toxic, as designated by the U.S. Environmental Protection Agency (EPA), or present a lower risk to human health and the environment when compared to alternative chemicals and materials that also meet performance requirements; (2) from 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 produce than non-recycled substitute materials. There are a number of guidance documents and systems that can help select non-hazardous and sustainable chemicals and materials for various applications (see Appendix C). When analyzing low-impact chemicals and materials, trade-off analyses and performance testing may be required to ensure performance and reliability.

b. Optimize life cycle energy consumption and minimize environmental impacts by: (1) reducing the fully burdened cost of delivered energy, in accordance with Enclosure 7 of DoD Instruction 5000.02; (2) developing systems that employ energy efficient 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 renewable sources of energy.

c. Minimize life cycle wastes by: (1) reusing waste materials from manufacturing, use and end-of-life activities; (2) reusing system components and recycling materials to create new system components; (3) developing waste-to-fuel capabilities; and (5) integrating closed-loop system design.

d. Minimize the use of land or the transformation of land that degrades habitats and eco-systems.

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e. Prevent hazards that can occur throughout the life cycle by: (1) designing out or mitigating chemical, biological, or physical hazards; and (2) minimizing noise that can be harmful to system operators, surrounding populations, or wildlife.

4.3 Integrating Sustainability Analyses into Acquisition. To have the greatest influence on system design, Sustainability Analyses should be completed during early phases of acquisition. It can be used as early as the Analysis of Alternatives (AoA) phase. Appendix A explains in detail the appropriate phases for conducting a Sustainability Analysis (see FIGURE 2.). A Sustainability Analysis is most useful during trade studies in preliminary design and to support the Supportability Analysis and Affordability Analysis. It is also recommended that Sustainability Analyses be updated when more refined data become available after Milestone B (i.e., sustainment and disposal activities). Sustainability remains a factor throughout acquisition and should still be evaluated even if the system enters acquisition at a later phase, as directed by Materiel Development Decision (MDD) and authorized by the Milestone Decision Authority (MDA).

![FIGURE 2. Sustainability Analyses in acquisition phases](image)

4.4 Factors that influence a Sustainability Analysis. The level of rigor in Sustainability Analyses 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 (e.g., evolutionary or single step to full capability); and
e. As directed by the Program Manager (PM) and the MDA, if applicable.

For example, Sustainability Analyses for ACAT I acquisitions may be expansive and technically rigorous while ACAT III acquisitions may have smaller and narrowly focused Sustainability Analyses. Similarly, a Sustainability Analysis might be predominantly qualitative in the Pre-Systems Acquisition period due to a general lack of data and definition of the materiel solutions. Regardless of the ACAT designation, when acquisitions involve legacy platforms, past data from those systems should be used to support the Sustainability Analysis.
5. GENERAL OVERVIEW OF LIFE CYCLE ASSESSMENT (LCA)

In this guidance, streamlined life cycle assessment (SLCA) is introduced as the recommended approach for assessing resource consumption and impacts to the mission, human health and the environment. The SLCA is derived from the standardized method for conducting process-level LCA as documented in the ISO 14040 series. The SLCA is a more simplified approach than process-level LCA, but is preferable if organizational resources are limited (e.g., time and data).

The following sections briefly describe and contrast process-level LCA to the SLCA methodology presented in this guidance document.

5.1 Introduction to Process-Level Life Cycle Assessment (LCA). LCA is a methodology used to assess human health and environmental impacts associated with all the life cycle stages associated with a product or process (i.e., from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling). Process-level LCA, as standardized by ISO 14040, utilizes mass and energy balance techniques to quantify the flow of resources into the system and emission outputs from the system for all processes that compose the system. Once all flows have been quantified, system outputs are then translated into various units of human health and environmental impacts (e.g., kg CO$_2$eq). Per ISO 14040, a process-level LCA divides this analysis into the following four phases:

a. Goal and scope definition. A LCA starts with an explicit statement of the goal and scope of the study, which determines the context of the study and explains how and to whom the results are to be communicated. This phase defines: (1) the intended application of the study; (2) the product or system to be studied; (3) the functional unit of the product or system; and (4) the boundaries of the product or system.

b. Life cycle inventory (LCI) analysis. A LCI analysis involves creating an inventory of flows from and to nature for the system. Inventory flows include inputs of water, energy, and raw materials, and releases to air, land, and water (see 3.2.21). To develop the inventory, a flow model of the technical system is constructed using data on inputs and outputs. The flow model is typically illustrated with a flow chart that includes the activities that will be assessed in the relevant supply chain and provides a clear picture of the technical system boundaries. The input and output data needed for the construction of the model are collected for all activities within the system boundary, including from the supply chain. Output data are frequently difficult to measure, in which case models and calculations utilizing emission factors (see 3.2.10) that are tied to specific processes or activities are used to estimate system outputs. FIGURE 3 shows the basic steps involved in a LCI analysis.

c. Life cycle impact assessment (LCIA). Inventory analysis is followed by impact assessment, which evaluates the significance of potential environmental impacts based on the LCI flow results. This step requires evaluators to translate output data from the LCI into estimated impacts, categorized into predefined categories (i.e., impact categories, see 3.2.15), by using characterization factors (see 3.2.4) from an established life cycle impact assessment (LCIA) methodology. There are several different LCIA methodologies that use different assumptions and models to translate LCI results into impacts. However, all
LCIA methodologies are based on scientific literature that encompass fate and transport modeling in accordance with the fields of toxicology, epidemiology, ecology, and climate science. FIGURE 3 shows how characterization factors are used to translate LCI results into estimated impacts.

d. Interpretation. Life cycle interpretation is a systematic technique used to identify, quantify, check, and evaluate information from the results of the life cycle inventory and the life cycle impact assessment. The interpretation phase should deliver results that: (1) are consistent with the defined goal and scope of the study; (2) explain study limitations; and (3) provide recommendations.

The ISO 14040 series of standards and ILCD handbook\textsuperscript{7} provide additional guidance for conducting a process-level LCA.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{lca_flowchart.png}
\caption{Process flow diagram for LCA methodology}
\end{figure}

5.2 Introduction to Streamlined Life Cycle Assessment (SLCA). The purpose of the SLCA is to compare two or more systems, sub-systems, or components with the same function (i.e., alternate systems with similar expectations of performance) on the basis of potential for mission,\textsuperscript{7} European Commission Joint Research Center ILCD handbook is available at http://lct.jrc.ec.europa.eu.
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 (see 6.6). Results are amenable to visual presentation using spider web diagrams that illustrate relative values and the magnitude of those values. The results inform product or process design analyses and provide decision support for decision makers who seek to meet sustainability goals.

NOTE: The SLCA method is only designed for relative comparisons between two or more systems. Unlike traditional LCA techniques established under the ISO 14040 series, SLCA results should not be interpreted as absolute values. Instead, the resulting impact values from the SLCA model represent each alternative’s position, relative to all other alternatives, within a specified impact category.

The SLCA method was tailored to enhance existing environmental and cost assessments, as well as sustainability efforts, within defense acquisition. Specifically, the SLCA was designed to aid decision makers in comparing alternatives according to elements of sustainability at any phase of acquisition. As such, the boundaries of the assessment and the life cycle phases of acquisition are integrated. These boundaries includes four general phases: (1) raw material acquisition; (2) production and deployment; (3) operation and sustainment (O&S); and (4) disposal. A simplistic, high-level mapping of the system acquisition process is illustrated in FIGURE 4, which shows the life cycle phases of a system to be included in a SLCA. These general boundaries may not apply to all SLCAs and can be adjusted on a case-by-case basis.

The SLCA methodology was developed to evaluate impact for areas of concern (see 3.2.2) that are consistent with existing DoD policies, activities and practices. Each area of concern comprises impact categories that are related to resources (i.e., inputs) needed by a system or

![FIGURE 4. SLCA study boundaries](image-url)
component throughout its life cycle. These impacts are categorized according to the following six areas of concern:

a. **Mission**: impacts that affect the ability of defense personnel to complete the mission.
b. **Human Health**: direct health impacts to defense personnel or surrounding communities that could result in additional costs to the DoD.
c. **Ecosystem Health**: direct health impacts to wildlife that negatively impact surrounding ecosystems and could result in additional costs to the DoD.
d. **Air**: atmospheric impacts that could indirectly affect human and environmental health and lead to additional remediation and other costs to the DoD.
e. **Water**: impacts to water systems or the earth’s hydrological cycle that could indirectly affect human and environmental health and lead to additional remediation and other costs to the DoD.
f. **Land**: impacts to established ecosystems from land development that could indirectly affect human and environmental health and lead to additional remediation and other costs to the DoD.

The SLCA comprises a series of steps intended to inventory resource requirements and model the relative impacts associated with a system compared to other systems being evaluated (see 6). This method evaluates the energy, water, land, and chemical and material inputs to the system and the associated emissions and waste outputs generated across that system or component’s life cycle. This process is streamlined in that evaluators are not required to measure or model a system’s outputs. Specifically, the SLCA methodology utilizes scoring factors to simultaneously estimate system outputs using generalized emission factors (see 3.2.13) and characterizes those outputs into life cycle impacts by using characterization factors (see 3.2.4) derived from risk assessment and LCIA methodologies (see Appendix F). FIGURE 5 summarizes the SLCA methodology.

NOTE: Noise is a system output. Unlike other system outputs (e.g., emission to air and water effluent), the estimate of noise output is not modeled using scoring factors or characterization factors. As illustrated in FIGURE 5, the quantity of noise output is directly translated to human health and ecosystem health impacts. The estimates of the quantity of noise output can be based on: (1) measurements at the source, or (2) estimates using proxy data from legacy systems, predictive models, or expert elicitation.

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8 For further explanation on emission factors, see Notes & Sources in the SLCA tool available at [http://denix.osd.mil/esohacq/](http://denix.osd.mil/esohacq/).
The SLCA framework (see FIGURE 6) 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 impacts from those inputs are assigned. (Note: human and ecosystem noise impacts have a dotted outline in FIGURE 6 because they do not result from the inputs mentioned above). Due to the streamlined nature of the SLCA method, evaluators are only required to record the inputs needed by the system across its life cycle. The inventory of these inputs includes the type, source, and quantities used by the system and to support and maintain the system. As illustrated in FIGURE 6, inputs are not mutually exclusive to impact categories. For example, energy use...
can result in impacts across multiple categories within the mission, human health and air areas of concern.

Input data for the SLCA can be collected from multiple sources. Sources of data may include, but are not limited to: (1) purchase records from similar existing platforms and legacy systems; (2) sustainment data for operation and maintenance of similar existing platforms and legacy systems; (3) an estimated bill of materials informed by initial designs or technology development activities; (4) use of inputs from initial tests during technology development; and (5) parametric estimates of input use or consumption during operation and sustainment phases.

After collecting data for all system inputs, the SLCA methodology translates the use of resources into impacts to mission, human health and the environment. Unlike traditional LCIA methodologies used in a process-level LCA, the resulting impacts from a SLCA are characterized using scoring factors that are generalized across all potential activities. These results should not be considered as robust as those calculated using traditional process-level LCA described in the ISO 14040 series.

![FIGURE 6. Streamlined life cycle assessment (SLCA) framework](image)

5.3 Differences between SLCA and Process-Level LCA. In general, the SLCA presented in this guidance document (see 6) comprises the same phases (i.e., goal and scope definition,
inventory analysis, impact assessment, and interpretation) as a process-level LCA. There are, however, noteworthy differences between the SLCA and process-level LCA.

First, the SLCA provides guidance on defining the goal (see 6.1), scope (see 6.2), and boundaries (see 6.3) of the assessment in a manner that is tailored to defense acquisition. A process-level LCA typically comprises all life cycle stages of a system or product – (1) raw material acquisition; (2) production and deployment; (3) operation and sustainment (O&S); and (4) disposal. In contrast, the SLCA limits the system boundaries to include only those life cycle stages for which the DoD has direct influence (see 6.3). Therefore, the raw material acquisition life cycle stage of systems may be excluded from some assessments.

Second, the SLCA differs from traditional LCA by alleviating the data collection burden when building a LCI (see 3.2.21). The SLCA does not require evaluators to specify activities or processes that occur within the system boundaries (see 6.3) and quantify the resulting system outputs (e.g., emissions and environmental releases) from those specified activities or processes. (NOTE: The level of noise output should be quantified, as illustrated in FIGURE 5). Instead the SLCA utilizes scoring factors and qualitative scoring methods to: (1) characterize the inventory of inputs into impacts; and (2) quantify the magnitude of impact within each impact category without attributing emissions to specified activities or processes. FIGURE 7 provides a visual explanation for how the SLCA methodology differs from traditional methodology used in process-level LCA.

Third, the generalized impact calculations resulting from the SLCA methodology are intended to quantify the relative magnitude between alternatives and should only be used to compare impact categories for two or more systems, sub-systems, or components with the same function (i.e., alternate systems with similar expectations of performance). Conversely, results from traditional LCA methods can standalone and be considered as absolute. More specifically, the two methods differ in that:

a. LCA accurately quantifies impacts within areas of concern and provides precise (i.e., repeatable results) comparisons of alternatives within and across impact categories; whereas
b. SLCA is not necessarily accurate in quantifying the absolute value of a particular impact, but is precise in identifying alternatives with the lowest impact by estimating a relative magnitude of difference in impact between alternatives within a particular impact category.

Given that the purpose of the SLCA is for comparative assessment, the methodology was developed to intentionally emphasize precision over accuracy. As such, the results of the SLCA cannot be interpreted as standalone or absolute values and are only useful when comparing two or more systems, subsystems or components. Since evaluators must compare alternatives under time and resource constraints, it is more important to discern which alternative results in the least impact, relative to other alternatives, than quantify the actual value of that impact. Therefore, the SLCA is the preferred method for comparing the alternatives across the six areas of concern.

6. CONDUCTING THE SLCA

There are six 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 a Life Cycle Inventory (Section 6.4)
STEP 5: Assessing Mission, Human Health, and Environmental Impacts (Section 6.5)
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 in the 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 or specification. It is critical that the functional unit be the same for all systems or components being assessed.

NOTE: Both the 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 is expected to have a life span of 50 years. Thus, two units of Alternative X are needed to meet the minimum capability requirements, while only one unit of Alternative Y is needed. In this example, one unit of Alternative Y may have greater 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 may be 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, implying that Alternative X must complete twice the number of trips as Alternative Y in order to fulfill the capability. Alternative Y may be less fuel efficient than Alternative X. However, since Alternative X has to complete 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. 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, 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 among all alternatives.

A simplistic, high-level mapping of the system acquisition process is illustrated in FIGURE 4 (see 5.2). FIGURE 4 also shows the life cycle phases to be included in a SLCA, which are Raw Materials Acquisition, Production/Deployment, O&S, and Disposal. The general boundaries illustrated in FIGURE 4 may not apply to all SLCAs and can be adjusted on a case-by-case basis.
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.

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

Best practice dictates that a justification should be provided if the following are excluded from the 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 should remain the same for all alternatives to maintain the integrity of a comparative assessment.

6.4 Building a Life Cycle Inventory (LCI). Building the LCI for a SLCA requires collecting data on the resources that a system will use and the amount of noise that it will emit throughout its life cycle. The LCI data collected for each alternative should be grouped according to the following general input and output categories:

a. System Inputs
   1) Energy
   2) Chemicals and Materials
   3) Water
   4) Land

b. System Outputs
   1) Noise

The following sections provide guidance on how to collect data on a system’s life cycle resource requirements life cycle resource requirements (i.e., system inputs) as well as noise output.

6.4.1 Energy. 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 during operation. For example, the diesel used to fuel a ground vehicle is direct energy. Indirect energy is not consumed directly by the system during operation, but is necessary to manufacture, sustain (e.g., maintain, transport, decommission) 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 B 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 should assign quantities to each type of energy that is consumed. Guidance is provided in 6.4.7 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) and British Thermal Units (BTUs), or measures of energy carriers, such as cubic feet (ft³) of natural gas and gallons 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 B.

6.4.2 Chemicals and Materials. To the greatest extent possible, evaluators should identify chemicals and materials that are prevalent within the system boundaries (see 6.3) throughout its life cycle. Prevalent chemicals and materials are those that are used by, consumed by, or released by the system during its life cycle. When completing the chemical and material inventory for the SLCA, it is helpful to use purchase records, safety data sheets, and emission inventories when available to identify hazardous chemicals and materials. A list of chemicals and materials is provided in Appendix B and incorporated into the SLCA tool developed for defense acquisition (see 6.5.1).

NOTE: The list in Appendix B is not exhaustive and represents those chemicals and materials for which the risk of impact can be characterized by using scoring factors that are based on established scientific research. There are hundreds, if not thousands, of chemicals and materials that may be prevalent within the established system boundaries throughout the life cycle. Evaluators should use expert judgment on chemicals and materials that should 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; or (3) critical to the system. Evaluators should note that if a prevalent chemical or material is not listed in Appendix B, this does not imply that the chemical or material possesses no risk. Instead, it is possible that the chemical or material of interest lacks scientific evidence of impact risk. This is especially true for newly developed chemicals and materials. In such cases, evaluators should consult with subject matter experts to assess the risk of impact that the chemical or material poses. Furthermore, evaluators may consider modeling the composing constituents of the chemical or material of interest when that chemical or material is not on the list (see Appendix B).

After identifying the chemicals and materials prevalent within a system throughout its life cycle, evaluators should assign quantities to each chemical and material. Safety data sheets can provide general quantity estimates when more refined data are unavailable. General guidance is provided in 6.4.7 on collecting quantity data as well as how to assess quantity when data are unavailable. The amount of chemicals and materials should be recorded in units of mass (i.e., kilograms). When using the SLCA tool (see 6.5.1), chemical and material input data should be recorded in units specified in Appendix B.
6.4.3 Water. When collecting data on water use, evaluators should consider all direct and indirect uses of water during a system’s life cycle. Direct water composes water required to operate the system, including all subsystem components. In contrast, indirect water constitutes the water required to manufacture, sustain (e.g., maintain, transport, decommission) 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 8 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 8. Flow diagram for system water use**

In order to assess water use efficiency, evaluators should 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 should be assessed for each activity or process that uses water, either directly or indirectly, throughout a system’s life cycle. Guidance is provided in 6.4.7 on how to collect quantitative data and 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 typically considered in a SLCA, but can be incorporated by evaluators as needed.

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 classify the land type (i.e., ecosystem designation) of 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>
<thead>
<tr>
<th>Land Type</th>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture – High Intensity</td>
<td>Agri_hi</td>
<td>conventional arable, integrated arable, organic arable, fibre/energy crops, intensive meadow</td>
</tr>
<tr>
<td>Agriculture – High Intensity</td>
<td>Agri_li</td>
<td>less intensive meadow, organic meadow, organic orchard, natural grassland</td>
</tr>
<tr>
<td>Artificially Built Environment –</td>
<td>Artificial_hi</td>
<td>Built up land, continuous urban, discontinuous urban, sport facilities, industrial area – part with vegetation</td>
</tr>
<tr>
<td>High Intensity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Artificially Built Environment –</td>
<td>Artificial_li</td>
<td>Green urban, rural settlement, rail embankments</td>
</tr>
<tr>
<td>Low Intensity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forest – High Intensity</td>
<td>Forest_hi</td>
<td>Forest plantations</td>
</tr>
<tr>
<td>Forest – Low Intensity</td>
<td>Forest_li</td>
<td>Semi-natural broad-leaved forest (either moist or arid)</td>
</tr>
<tr>
<td>Non-use</td>
<td>Non-use</td>
<td>Heathland, hedgerows, peatbog</td>
</tr>
</tbody>
</table>

6.4.5 Noise. When collecting data for noise output, evaluators should consider the increase in noise resulting from the use of the system and how the resulting noise affects people, ecological receptors, or structures on or in areas in proximity of a military installation. The estimates of the quantity of noise output can be based on: (1) measurements at the source; or (2) estimates using proxy data from legacy systems, predictive models, or expert elicitation.

Evaluators should consider the population size of the exposure groups and the level of exposure to include, but not limited to, the duration of exposure and the distance from the noise source. Exposure should be estimated based on measurements or proxy data reported in the most applicable units, usually A-weighted decibels (dBA). Existing DoD occupational and environmental health-related exposure monitoring data may be used to estimate the quantity of noise output. If using the SLCA tool developed for defense acquisition (see 6.5.1), noise output data should be recorded in dBA.

6.4.6 Life Cycle Activity Profile. As part of building an input inventory, evaluators should complete a Life Cycle Activity Profile for each alternative being considered. This is a critical step in the SLCA process. The Activity Profile will identify all major resource requirements and activities throughout the life cycle boundaries that are likely to have impacts. The purpose of an
Activity Profile is to efficiently inform a SLCA, while at the same time reduce 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 Analysis.

It is important to note that the results of an Activity Profile can enhance life cycle costing
efforts by identifying typically hidden costs (e.g. indirect costs, costs associated with future or
contingent liabilities, and external costs). Hidden costs frequently result from impacts that occur
during production and deployment of a system, sustainment activities and disposal.

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

a. Identify the appropriate activity descriptors (see 3.2.1) for a system or component (i.e.,
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 important system or component activity descriptors (see 3.2.1) 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 activity
descriptors (i.e., 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 can be found in Appendix D.

**TABLE 2. Example system/components organized by energy activity descriptors**

<table>
<thead>
<tr>
<th></th>
<th>Stationary</th>
<th>Mobile</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Active</strong></td>
<td>(a) HVAC System, Water purification System, etc.</td>
<td>(b) Aircraft, Ground Vehicle, Ship, etc.</td>
</tr>
<tr>
<td><strong>Passive</strong></td>
<td>(c) Satellite Dish, Barricade Infrastructure, etc.</td>
<td>(d) Trailer, Satellite, Bomb, etc.</td>
</tr>
</tbody>
</table>

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 does not move on its own accord, but rather is mobilized using support systems. A passive mobile system does not directly consume resources during its operation to achieve its function.

NOTE: The Activity Profile is an activity focused on system inputs (i.e., energy, chemicals and materials, water and land), as the activity descriptors are strong indicators for how inputs will be used by an alternative throughout the life cycle. Although the general concepts composing the Activity Profile may be used to help evaluators identify possible sources of noise outputs, these activity descriptors do not necessarily indicate trends for system outputs, and therefore, may not inform data collection efforts relating to noise output.

By defining key activity descriptors for each alternative, evaluators can better identify the activities and life cycle phases that consume the most resources (i.e., energy, chemicals and materials, water and land). After activity descriptors have been defined, evaluators can enter those activities into a Life Cycle Activity Profile. TABLE 3 provides a template for completing the Life Cycle Activity 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 E). Once completed, an Activity Profile guides SLCA data collection by identifying: (1) the resources a system uses; and (2) the life cycle phases during which those resources are consumed. This helps evaluators focus data collection gathering efforts.

### TABLE 3. Example life cycle activity profile template

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Life Cycle Phases</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Raw Materials Acquisition</td>
</tr>
<tr>
<td>Energy</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td></td>
</tr>
<tr>
<td>Chemicals &amp; Materials</td>
<td></td>
</tr>
<tr>
<td>Land Use</td>
<td></td>
</tr>
</tbody>
</table>

6.4.7 **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 the data are 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 qualitatively score or rank alternatives based on estimates of system inputs (i.e., energy, chemicals and materials, water and land) and noise output. The following sections provide
guidance on how to: (1) collect and use quantitative data (see 6.4.7.1); (2) qualitatively score alternatives (see 6.4.7.2) based on estimated resource requirements; and (3) rank alternatives based on estimated resource requirements (see 6.4.7.3). Users should note that qualitative scoring captures both order and magnitude of difference between two or more alternatives, whereas rank only captures the order of those alternatives.

Data collected on energy, chemicals and materials, water and land must be consistent across all alternatives being assessed. For example, if quantitative data are collected on the energy use of one alternative, quantitative data should be collected on the energy use of all alternatives in the assessment. Conversely, if a qualitative scale is used for a specific input category, the same qualitative scale must be used for all alternatives. Consistency in the type of data that are used to compare alternatives is important because the comparison is based on relative SLCA results and will result in the highest level of precision.

Quantitative data, relative scoring, and ranking can be used in the same assessment as long as the same data type for a given input is used across all alternatives being assessed. This flexibility is a significant advantage of the SLCA developed for DoD.

6.4.7.1 Quantitative Data. Quantitative life cycle data should be continually collected throughout all phases of acquisition, including the systems engineering process, manufacturing and productions, deployment, sustainment and disposal 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 should ensure that the function and operation of the legacy system closely resembles the proposed function and operation for the alternative being assessed.

6.4.7.2 Qualitative 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 engineering judgment for both the order of performance (i.e., best to worst), as well as an estimated magnitude of difference in performance among 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 or noise output and across all alternatives.

6.4.7.3 Ordinal Ranking. If evaluators are unable to estimate the general magnitude of difference in resource use or noise output between two alternatives, evaluators should rank those alternatives according to the best through worst performing for that given resource or noise
output. It is important to note that when assigning an ordinal rank, the magnitude of difference among alternatives will not be captured. Evaluators should also be aware that two or more alternatives can have the same ordinal rank if those alternatives consume the same amount of a given resource or noise output. If this is the case, the next best option should 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**

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative A</td>
<td>1</td>
</tr>
<tr>
<td>Alternative B</td>
<td>1</td>
</tr>
<tr>
<td>Alternative C</td>
<td>2</td>
</tr>
<tr>
<td>Alternative D</td>
<td>3</td>
</tr>
<tr>
<td>Alternative E</td>
<td>4</td>
</tr>
<tr>
<td>Alternative F</td>
<td>4</td>
</tr>
<tr>
<td>Alternative G</td>
<td>5</td>
</tr>
</tbody>
</table>

6.5 Assessing Human Health and Environmental Impacts. System life cycle data on energy, chemicals and materials, water, land and noise⁹ are used to assess impacts to mission, human health and the environment. There are a total of 19 impact categories (TABLE 5). These categories are grouped into six general areas of concern: Mission, Human Health, Ecosystem Health, Air, Water and Land.

**TABLE 5. Impact categories organized by areas of concern**

<table>
<thead>
<tr>
<th>Areas of Concern</th>
<th>Impact Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mission</td>
<td>Fossil Fuel Depletion</td>
</tr>
<tr>
<td></td>
<td>Energy Source Reliability</td>
</tr>
<tr>
<td></td>
<td>C&amp;M Availability</td>
</tr>
<tr>
<td></td>
<td>C&amp;M Recovery</td>
</tr>
<tr>
<td></td>
<td>Total Water Use</td>
</tr>
<tr>
<td>Human Health</td>
<td>Respiratory Effects</td>
</tr>
<tr>
<td></td>
<td>Human Toxicity</td>
</tr>
<tr>
<td></td>
<td>Human Noise</td>
</tr>
<tr>
<td>Ecosystem Health</td>
<td>Ecological Toxicity</td>
</tr>
<tr>
<td></td>
<td>Ecosystem Noise</td>
</tr>
<tr>
<td>Air</td>
<td>Global Warming</td>
</tr>
<tr>
<td></td>
<td>Ozone Depletion</td>
</tr>
<tr>
<td>Water</td>
<td>Smog Formation</td>
</tr>
<tr>
<td>Land</td>
<td>Water Loss</td>
</tr>
<tr>
<td></td>
<td>Water Degradation</td>
</tr>
<tr>
<td></td>
<td>Water Scarcity</td>
</tr>
<tr>
<td></td>
<td>Land Degradation</td>
</tr>
</tbody>
</table>

⁹ Noise is not a system input, but instead, a system output. However, for purposes of the SLCA model, it is treated the same as a system input.
There are two approaches for assessing impacts based on the gathered LCI 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 provided in Appendix B. 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 provides evaluators with a structured and automated vehicle for carrying out each step of the SLCA data collection and entry process. The SLCA tool and directions on how to use the tool can be accessed at [http://denix.osd.mil/esohacq](http://denix.osd.mil/esohacq). *Evaluators should note that the current version of the tool (v2.41) is a beta version intended to demonstrate and test the automated capabilities of the SLCA methods described in this guidance. This current version of the tool, which exists as a Microsoft Excel file, will be replaced by a web-based software application that is currently under development.*

The SLCA tool provides evaluators with a structured vehicle for carrying out each step of the SLCA data collection and entry process. This tool also simplifies the characterization of inputs into comparable impact units for each impact category and simplifies the assessment for evaluators by completing all calculations for the user; including indexing those resulting impacts into relative scores that can be compared across impact categories. In doing so, this tool significantly reduces the amount of time needed to complete the SLCA. When using the tool, users are only required to set the modeling parameters of the study, as detailed in the tool directions, and enter all relevant resource input and noise output data into the appropriate data input tables within the tool. TABLE 6 provides a detailed list, by resource type, of all input tables in the tool and their respective worksheets within the tool.

<table>
<thead>
<tr>
<th>Resource</th>
<th>Worksheet</th>
<th>Input Table</th>
<th>Inputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>Input - Energy</td>
<td>Input Table 1</td>
<td>Stationary Combustion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Input Table 2</td>
<td>Mobile Combustion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Input Table 3</td>
<td>Electricity Consumption</td>
</tr>
<tr>
<td>Chemicals and Materials</td>
<td>Input – C&amp;M</td>
<td>Input Table 4</td>
<td>Chemicals and Materials</td>
</tr>
<tr>
<td>Water</td>
<td>Input - Water</td>
<td>Input Table 5</td>
<td>Quantity of Input/output Water by Source</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Input Table 6</td>
<td>Quantity of Water Use by Activity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Input Table 7</td>
<td>Water Degradation Score by Activity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Input Table 8</td>
<td>Quantity of Water Use in Scarce Regions by Applicable Scarcity Region</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Input Table 9</td>
<td>Water Scarcity Score by Applicable Region</td>
</tr>
<tr>
<td>Land</td>
<td>Input - Land</td>
<td>Input Table 10</td>
<td>Land Transformation by Ecosystem Designation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Input Table 11</td>
<td>Land Occupation Time by Transformation Type</td>
</tr>
<tr>
<td>Noise</td>
<td>Input - Noise</td>
<td>Input Table 12</td>
<td>Noise Output to Human Populations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Input Table 13</td>
<td>Noise Output to Wildlife Populations</td>
</tr>
</tbody>
</table>
Finally, the tool provides evaluators with a visual dashboard that presents the data in three formats: (1) a table of normalized results; (2) a bar graph of the normalized results; and (3) a spider-web diagram that compares sustainability footprints of evaluated alternatives across all impact categories. This visual dashboard can be used to identify high-risk impact categories for each alternative and better inform tradeoffs during design and technology development activities.

6.5.2 Assessing impacts manually. Evaluators may complete the SLCA without using the SLCA tool. The following sections provide guidance on how to manually calculate impacts from resource consumption, as identified in the life cycle inventory (see 6.4). A complete list of scoring factors used for scoring impacts can be accessed at http://denix.osd.mil/esohacq. Evaluators should refer to the “Notes and References” and “Sources” worksheets within the SLCA tool for an explanation of the methodology and sources used for developing the scoring factors. Guidance on how to calculate the impact for each impact category is provided below.

6.5.2.1 Fossil Fuel Depletion. The use of fossil fuels impacts the DoD’s mission by potentially reducing access to future energy resources. The term fossil fuel refers to a group of resources that contain hydrocarbons, which range from volatile materials like methane, to more stable liquid petroleum products, to non-volatile materials like coal. The goal of this impact category is to ensure that: (1) evaluators consider the amount of fossil fuels used by each evaluated alternative; and (2) renewable sources of energy are used by the system when possible. For the purpose of scoring alternatives in this impact category, Appendix B provides scoring factors \( S_{F_i} \) for each energy type \( t \) recorded in 6.4.1. These scoring factors compare the availability, in terms of available reserves, of each type of fossil fuel.

Instead of using calculated geological fossil fuel reserves, the scoring factors rely on the estimated marginal cost of consumption (MCC) (see 3.2.22) to provide a proxy for estimating the relative difference among those reserves. The MCC is used as a proxy for fuel availability because the actual availability of conventional fossil fuels, especially liquid crude oil, is highly controversial. Projections of fossil fuel resources vary considerably and are not reliable for use when estimating a particular fuel’s resource depletion potential. However, most fossil fuels are commodities traded on regional or worldwide markets, for which prices can communicate trends in available supply. Assuming that these markets are efficient, the price of the last unit of fuel sold will equal the marginal cost of consuming that unit, which provides a good indicator of the trend for the DoD’s supply. More specifically, when conventional fossil fuel production is limited by scarcity, new (i.e., unconventional) sources of that fuel will be needed to ensure sufficient supply. Unconventional fossil fuel resources are generally more energy intensive and more costly to produce compared to conventional fuels; and thus, these unconventional fuels will only be produced when the overall price for the fuel is high enough to cover higher production costs. So in an efficient market, the price of a particular fossil fuel will be determined by the cost of the most expensive unconventional fuel that is needed to satisfy demand. The MCC normalizes the market price to units of energy (i.e., British Thermal Units) so that all fuels can be compared.

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10 Increasing prices indicate reductions in the supply of conventional fuels relative to demand, whereas decreasing prices indicate increases in the supply of conventional fuels relative to demand.
NOTE: Renewable and non-fossil fuels all have MCCs of zero because there is no potential for supply disruption due to fossil fuel depletion.

To calculate the actual cost of fossil fuel depletion 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 B, or in accordance with 6.4.7 when quantitative data is not available, and should include both direct and indirect energy. Equation 1 summarizes this calculation below.

\[
FFD_x = \sum_{t=1}^{n} Q_t \times SF_t
\]

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 relatively 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 should first assign a risk score to each criterion in accordance with TABLE 7 below.

<table>
<thead>
<tr>
<th>Risk Level</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>0</td>
</tr>
<tr>
<td>Very Low</td>
<td>1</td>
</tr>
<tr>
<td>Low</td>
<td>2</td>
</tr>
<tr>
<td>Medium</td>
<td>3</td>
</tr>
<tr>
<td>High</td>
<td>4</td>
</tr>
<tr>
<td>Risk Level</td>
<td>Score</td>
</tr>
<tr>
<td>------------</td>
<td>-------</td>
</tr>
<tr>
<td>Very High</td>
<td>5</td>
</tr>
</tbody>
</table>

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.

\[
WRS_x = 2 \times \sum_{t=1}^{n} \left[ (S_t + E_t + R_t) \times \left( \frac{TE_t}{TE_X} \right) \right]
\]

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 as compared to others. 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 (e.g., 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 should first assign a risk score to each criterion in accordance with TABLE 8 below.

<table>
<thead>
<tr>
<th>Risk Level</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>0</td>
</tr>
<tr>
<td>Very Low</td>
<td>1</td>
</tr>
<tr>
<td>Low</td>
<td>2</td>
</tr>
<tr>
<td>Medium</td>
<td>3</td>
</tr>
<tr>
<td>High</td>
<td>4</td>
</tr>
<tr>
<td>Very High</td>
<td>5</td>
</tr>
</tbody>
</table>

Once each criterion for a 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.

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

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. Recovering chemicals and materials for the purpose of reuse—either in the evaluated 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 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, evaluators 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.

\[ RPS_X = \left[ 1 - \left( \sum_{t=1}^{n} \frac{R_t}{T_x} \right) \right] \times 10 \]

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 should 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 sometimes scarce and diminishing in certain areas, or 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 use, 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 5 summarizes this calculation below.

\[ W_x = \sum_{t=1}^{n} Q_t \]

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, emits 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 according to potential respiratory effects, Appendix B 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 B, or in accordance
with 6.4.7 when quantitative data is not available, and should include both direct and indirect energy. Equation 6 summarizes this calculation below.

\[ RES_x = \sum_{t=1}^{n} Q_t \times SF_t \]

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 Human Toxicity. Hazardous 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 and materials that could significantly increase the probability of negative human health impacts (cancer and non-cancer) given elevated levels of exposure, and consider system or component designs that eliminate the use of these chemicals and materials. For the purpose of scoring alternatives in this impact category, Appendix B provides scoring factors \((SF_t)\) for each chemical and material \(t\) recorded in 6.4.2. These scoring factors are used to represent the collective steps along the cause-effect chain starting with the emission of chemicals and materials into an environmental compartment (i.e., air, soil and water), 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 or material’s potency (i.e., its potential to have adverse health impacts for humans).

The scoring factors characterize impacts to human health\(^{11}\) by accounting for: (1) the transport of these emissions through environmental media to the exposed population via exposure routes (i.e., inhalation and ingestion); and (2) the change in disease probability due to the lifetime intake of a particular chemical or material. It is important to note that these scoring factors simplify impact characterization by generalizing each chemical and material’s probability of emission into the air, soil and water. For most chemicals and materials prevalent within the system (see 6.4.2), these scoring factors assume that the specified chemical or material will be equally emitted (i.e., default emission assumptions) into each environmental medium upon its release from the system (e.g., 33.33\% into the air, 33.33\% into the soil and 33.33\% into the water). Some of the chemicals and materials provided in Appendix B present hazards to human health only when transported through one or two of the three environmental media. The default emission assumptions for those chemicals and materials were adjusted to reflect these unique conditions.

Users of the SLCA tool can change the default emission assumptions for as many chemicals and materials as desired. Instructions for changing these assumptions are embedded within the SLCA tool. For more information on the SLCA tool see 6.5.1.

NOTE: Human toxicity results can vary significantly depending on the environmental media into which a chemical or material is emitted. This implies that the same chemical or material will have different impacts on human toxicity depending on whether the emission is to air, water

\(^{11}\) Human health impact is represented by the total increase in toxicity cases, measured as comparative toxic units (CTU) per kilogram of chemical or material emitted
or soil. Evaluators should note that the default emission assumptions for the SLCA method: (1) do not represent actual emission distributions into the three environmental media; (2) are not based on actual scientific findings; and (3) are intended to characterize an “average” toxicity impact by averaging the characterization factors across the three environmental media.

When conducting a comparative assessment of alternatives in regard to human toxicity, use of the SLCA default emission assumptions will sometimes cause evaluators to identify an alternative with the smallest toxicity footprint that actually differs from the selection that would be made when using process-level LCA. Evaluators should be aware that this probability of disagreement (see 3.2.31) between SLCA and process-level LCA will increase as: (1) the number of chemicals and materials used by the system increase; or (2) the number of alternatives evaluated increase. Thus, the likelihood of disagreement between and process-level LCA and SLCA can be minimized by keeping the number of chemicals and materials and the number of alternatives at a relatively low number. FIGURE 9 summarizes how the probability of disagreement changes as both the number of chemicals and materials increases and number of alternatives evaluated increases.

To calculate the human toxicity score for alternative \( x \) (\( HTS_x \)), evaluators should sum the results of multiplying the quantity of each chemical or material used by the alternative (\( Q_t \)) by that chemical or material’s scoring factor (\( SF_t \)). \( Q_t \) should be recorded in units designated in
Appendix B or in accordance with 6.4.7 when quantitative data is not available, and should include both direct and indirect energy. Equation 7 summarizes this calculation below.

\[ HTS_x = \sum_{t=1}^{n} Q_t \times SF_t \]

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

6.5.2.8 Human Noise. Systems that emit high noise levels can adversely impact human health. The potential impacts from noise are determined by considering the population size of the exposure groups \( t \) and the level of exposure \( E_t \), including but not limited to, the duration of exposure and the distance from the noise source. Exposure should be measured in the most applicable units (e.g., A-weighted decibels (dBA)).

Each alternative’s impact to human health is calculated as the summation of each population’s level of noise exposure weighted by the population’s size (Equation 8).

\[ N_x = \sum_{t=1}^{n} P_t \times E_t \]

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.

6.5.2.9 Ecological Toxicity. Hazardous emissions to ecosystems present toxicity concerns for wildlife residing in those ecosystems. The goal of this impact category is to ensure that evaluators identify the use of hazardous chemicals and materials that could significantly increase the probability of ecological toxicity given elevated levels of exposure, and consider system or component designs that eliminate the use of these chemicals and materials. For the purpose of scoring alternatives in this impact category, Appendix B provides scoring factors \( SF_t \) for each chemical or material \( t \) recorded in 6.4.2. These scoring factors are used to represent the collective steps along the cause-effect chain starting with the emission of chemicals and materials into an environmental compartment (i.e., air, soil and water), followed by the fate and transport through the environment, exposure to wildlife, and the resulting effects on the exposed populations. A scoring factor for a chemical or material represents that chemical or material’s potency (i.e., its potential to have adverse impacts for wildlife).
The scoring factors characterize impacts to ecosystem health by accounting for: (1) the persistence of a chemical or material in the environment; and (2) the bioavailability of that chemical or material, represented by the fraction of its total mass dissolved. It is important to note that these scoring factors simplify impact characterization by generalizing each chemical and material’s probability of emission into the air, soil and water. For most chemicals and materials prevalent within the system (see 6.4.2), these scoring factors assume that the specified chemical or material will be equally emitted (i.e., default emission assumptions) into each environmental medium upon its release from the system (e.g., 33.33% into the air, 33.33% into the soil and 33.33% into the water). Some of the chemicals and materials provided in Appendix B present hazards to ecosystem health only when transported through one or two of the three environmental media. The default emission assumptions for those chemicals and materials were adjusted to reflect these unique conditions.

Users of the SLCA tool can change the default emission assumptions for as many chemicals and materials as desired. Instructions for changing these assumptions can be found in the instructions embedded within the tool. For more information on the SLCA tool see 6.5.1.

NOTE: Ecotoxicity results can vary significantly depending on the environmental media into which a chemical or material is emitted. This implies that the same chemical or material will have different impacts on ecotoxicity depending on whether the emission is to air, water or soil. Evaluators should note that the default emission assumptions for the SLCA method: (1) do not represent actual emission distributions into the three environmental media; (2) are not based on actual scientific findings; and (3) are intended to characterize an “average” toxicity impact by averaging the characterization factors across the three environmental media.

When conducting a comparative assessment of alternatives in regard to ecotoxicity, use of the SLCA default emission assumptions will sometimes cause evaluators to identify an alternative with the smallest toxicity footprint that actually differs from the selection that would have been made when using process-level LCA. Evaluators should be aware that the probability of disagreement (see 3.2.31) between SLCA and process-level LCA will increase as: (1) the number of chemicals and materials used by the system increase; or (2) the number of alternatives evaluated increase. FIGURE 10 summarizes the probability of disagreement changes as both the number of chemicals and materials increases and number of alternatives evaluated increases.

---

12 Ecosystem health impact is represented by the total increase in the fraction of freshwater species potentially impacted, measured as comparative toxic units (CTU) per kilogram of chemical or material emitted
To calculate the ecotoxicity score for alternative $x$ ($ETS_x$), evaluators should sum the results of multiplying the quantity of each chemical and material used by the alternative ($Q_t$) by that chemical or material’s scoring factor ($SF_t$). $Q_t$ should be recorded in units designated in Appendix B or in accordance with 6.4.7 when quantitative data is not available, and should include both direct and indirect energy. Equation 9 summarizes this calculation below.

$$ETS_x = \sum_{t=1}^{n} Q_t \times SF_t$$

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

6.5.2.10 Ecosystem Noise. Systems that emit high noise levels can adversely impact the health of marine mammals and other wildlife. The potential impacts from noise are determined by considering the population size of the exposure groups ($t$) and the level of exposure ($E_t$), including but not limited to, duration of exposure and the distance from the noise source. Exposure should be measured in the most applicable units (e.g., A-weighted decibels (dBA)).

Each alternative’s impact to ecosystem health is calculated as the summation of each population’s level of noise exposure weighted by the population’s size (Equation 10).
\[ N_x = \sum_{t=1}^{n} P_t \times E_t \]

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 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 B 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 B, or in accordance with 6.4.7 when quantitative data is not available, and should include both direct and indirect energy. Equation 11 summarizes this calculation below.

\[ GWP_x = \sum_{t=1}^{n} Q_t \times SF_t \]

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.

6.5.2.12 Ozone Depletion. The use of substances like chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and halogens in 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 B 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 B, or in accordance with 6.4.7 when quantitative data is not available, and should include both direct and indirect energy. Equation 12 summarizes this calculation below.

\[ ODP_x = \sum_{t=1}^{n} Q_t \times SF_t \]
\[ ODP_x = \sum_{t=1}^{n} Q_t \times SF_t \]

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.

**6.5.2.13 Smog Formation.** 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 B 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 B, or in accordance with 6.4.7 when quantitative data is not available, and should include both direct and indirect energy. Equation 13 summarizes this calculation below.

\[ SP_x = \sum_{t=1}^{n} Q_t \times SF_t \]

Within this metric, alternatives with a lower \(SP_x\) have lower potential for smog formation, and thus, should be preferred over other alternatives with higher scores.

**6.5.2.14 Water Loss.** 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, direct and indirect, lost to transformations. In accordance with FIGURE 8 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 14 summarizes this calculation below. Evaluators should favor alternatives with a smaller \(L_x\).

\[ L_x = \frac{F}{C + D + E + F} \]

**6.5.2.15 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. Evaluators should give preference to alternatives that degrade source water the least during use or actually improve water quality. Evaluators should compare alternatives according
to the difference in water quality between the total water input (i.e., direct and indirect) from the source and the water output (i.e., direct and indirect) after use. Less degradation 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 released into the environment.

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 9. There are 11 water quality categories described in TABLE 9 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 11, and the required quality of the output water, which is represented by the vertical axis in FIGURE 11. Evaluators should then plot the water use for each alternative on FIGURE 11. 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.

**TABLE 9. Water quality categories and descriptions**

<table>
<thead>
<tr>
<th>Category</th>
<th>Category Label</th>
<th>Water Quality Description</th>
<th>Water Quality Parameters</th>
<th>Example Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Ultrapure</td>
<td>Distilled or highly purified water that contains no physical, chemical, or microbial impurities</td>
<td>Conductivity ≤ 5 µS/m; TDS ≤ 10 mg/L</td>
<td>Process water for high purity applications</td>
</tr>
<tr>
<td>B</td>
<td>Drinking water (potable water)</td>
<td>Water that is considered safe to drink as defined by the health-based standards in the Safe Drinking Water Act</td>
<td>Absence of coliform bacteria, turbidity ≤ 0.3 NTU, below Maximum Contaminant Level (MCL) for nitrate, nitrite, metals, fluoride, and other regulated parameters</td>
<td>Most uses of water including but not limited to drinking water</td>
</tr>
<tr>
<td>C</td>
<td>Non-potable water</td>
<td>Water that does not meet the requirements of the Safe Drinking Water Act</td>
<td>Physical, chemical, or microbial parameters including turbidity, nutrients, microbial indicators</td>
<td>Irrigation, industrial process water, cleaning, cooling water</td>
</tr>
<tr>
<td>D</td>
<td>Captured Rain water</td>
<td>Water that is captured during storm events and stored without exposure to environmental contaminants</td>
<td>Conductivity, turbidity</td>
<td>Most uses of water, but would require additional treatment before being used for potable water</td>
</tr>
<tr>
<td>Category</td>
<td>Category Label</td>
<td>Water Quality Description</td>
<td>Water Quality Parameters</td>
<td>Example Uses</td>
</tr>
<tr>
<td>----------</td>
<td>----------------</td>
<td>----------------------------</td>
<td>--------------------------</td>
<td>--------------</td>
</tr>
<tr>
<td>E</td>
<td>Storm water</td>
<td>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.</td>
<td>Sediments, fuel components, pathogens, nutrients, and other chemical constituents depending on the intensity of a storm event and land use patterns.</td>
<td>Irrigation, groundwater recharge, some industrial uses but might require additional treatment.</td>
</tr>
<tr>
<td>F</td>
<td>Gray water</td>
<td>Water that has been used for most in-building or shipboard uses except toilet flushing.</td>
<td>Pathogens, soaps/surfactants, and organic chemicals including those found in flame retardants and insect repellants.</td>
<td>Irrigation, toilet-flushing, cleaning; additional treatment might be required depending on how the water was used previously.</td>
</tr>
<tr>
<td>G</td>
<td>Reclaimed (recycled) water</td>
<td>Water recovered from municipal wastewater that has been treated to control pathogens and solids.</td>
<td>Pathogens, nutrients, salts, chemical contaminants.</td>
<td>Non-potable and indirect potable applications, depending on level of treatment provided.</td>
</tr>
<tr>
<td>H</td>
<td>Brackish water</td>
<td>Water that contains between 500 and 3,000 ppm of total dissolved solids. Typically found in estuaries, coastal groundwater systems, and deep (&gt;1,000 ft) groundwater.</td>
<td>Conductivity, hardness, metals, nutrients, pathogens, corrosivity.</td>
<td>Some non-potable applications including industrial process water, cooling water; other applications might require additional treatment.</td>
</tr>
<tr>
<td>I</td>
<td>Salt water</td>
<td>Water that contains over 3,000 ppm of total dissolved solids.</td>
<td>Conductivity, hardness, metals, nutrients, pathogens, algae.</td>
<td>Cooling water; salt water is more dense than fresh water and also has a lower capacity to store dissolved oxygen.</td>
</tr>
<tr>
<td>J</td>
<td>Industrial wastewater</td>
<td>Used water from industrial applications including process water, washwater, and cooling water blowdown.</td>
<td>Pathogens, chemical contaminants, sediments, nutrients.</td>
<td>Possible to reuse or recycle within a specific industrial application or augment water for other (lower quality) water use needs onsite.</td>
</tr>
<tr>
<td>K</td>
<td>Untreated wastewater</td>
<td>Used water discharged from homes, business, cities, industry, and agriculture.</td>
<td>Pathogens, chemical contaminants, sediments, nutrients.</td>
<td>Water that poses a potential health and environmental risk due to potential prevalence of pathogens and toxic constituents.</td>
</tr>
<tr>
<td>Category</td>
<td>Category Label</td>
<td>Water Quality Description</td>
<td>Water Quality Parameters</td>
<td>Example Uses</td>
</tr>
<tr>
<td>----------</td>
<td>----------------</td>
<td>---------------------------</td>
<td>--------------------------</td>
<td>--------------</td>
</tr>
<tr>
<td>L</td>
<td>Radioactive Wastewater</td>
<td>Water from activities or events known to have radioactive characteristics</td>
<td>Radioactive compounds such as Cesium-137, Americium-241, Uranium 234,235, and 238, Plutonium 238,239/240, Radium 226 and Strontium 90</td>
<td>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)</td>
</tr>
</tbody>
</table>

The water degradation score ($WD_{sx}$) for a single plot (i.e., single type of use for a given alternative) is determined by the score designated in FIGURE 11 to the gradient plane in which that plot falls within. If the plot falls directly on one of the isoquant lines, then evaluators should score that plot as the average of the scores in the gradient planes directly above and below that line. For example, a system that inputs potable water (B) from the available source and outputs industrial wastewater (J) will result in a score of 9.25 because that plot falls on the line between the gradient planes assigned to the scores of 9.0 and 9.5. A score of 5 indicates 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 and probably requires little to no additional energy to clean that water when released by the system. A score below 5 is usually only applicable to wastewater treatment systems. A score of 10 indicates that the input and output water quality vary drastically for a given type of use ($n$), implying that the water has been severely degraded and intensive water treatment or special water handling will be required. A score of 10 is the worst possible score an alternative can earn and extremely rare.

Once the water degradation score is recorded for each use type for a given alternative, evaluators should translate those scores into a weighted average by multiplying $WD_{sx}$ by the percentage of total water used by that system or component that $V_x$ comprises (see Equation 15 and FIGURE 8).\(^\text{13}\)

\[
(15) \quad WD_x = \sum_{i=1}^{n} \frac{V_i}{(A + B + C)} \times WD_{sx} = \sum_{i=1}^{n} \frac{V_i}{(C + D + E + F)} \times WD_{sx}
\]

\(^{13}\) Total water used is the sum of total direct and indirect water ($A + B + C$ or $C + D + E + F$), see FIGURE 6.
6.5.2.16 Water Scarcity. The goal of this impact category is to 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 may 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 16. Evaluators should use TABLE 10 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

![FIGURE 11. Water degradation scoring diagram](image-url)
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 8).

\[
WS_x = \sum_{i=1}^{n} \frac{VW_i}{(A + B + C)} \times WSI_x = \sum_{i=1}^{n} \frac{VW_i}{(C + D + E + F)} \times WSI_x
\]

**TABLE 10. Water scarcity indexes, definitions, and calculations**

<table>
<thead>
<tr>
<th>Title</th>
<th>Definition</th>
<th>Input Data Needed</th>
<th>Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Water Supply Stress Index Model (WaSSI)</strong></td>
<td>Measures watershed stress by comparing water supply and demand for a specific area</td>
<td>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</td>
<td>WaSSI model (available at <a href="http://www.fs.fed.us/ccrc/tools/wassi.shtml">http://www.fs.fed.us/ccrc/tools/wassi.shtml</a>) outputs water supply and demand for particular timeframe. A ratio is provided comparing demand to supply. A low ratio ((&lt;&lt;1)) indicates less water stress, whereas a ration approaching or exceeding 1 represents much higher watershed stress.</td>
</tr>
<tr>
<td><strong>Global Water Risk Index (GWRI)</strong></td>
<td>Geographic Information System (GIS) overlays of hydrologic, climatologic, economic, demographic, planning, and business info per land area</td>
<td>Domestic, agricultural, and industrial water demand based on population density, urban and rural location, local water use data (metering), agricultural and industrial activities</td>
<td>Model and mapping tools available at <a href="http://www.water-risk-index.com/methodology.html">http://www.water-risk-index.com/methodology.html</a></td>
</tr>
</tbody>
</table>

6.5.2.17 **Land Degradation.** 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 (e.g., forests) to a built environment has a greater impact than converting less productive land (e.g., 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

---

14 Total water used is the sum of total direct and indirect water \((A + B + C \text{ or } C + D + E + F)\), see FIGURE 6.
state. For 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 (see 6.4.4). When dividing the incremental plot of land into ecosystem designations, evaluators should also record the amount of land, in acres, that would be consumed under each ecosystem designation. To calculate \( WART_x \), evaluators should 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 17 summarizes how \( WART_x \) should be calculated. This calculation should be made in terms of the functional unit (see 6.1).

\[
WART_x = \sum_{i=1}^{n} ED_x \times RT_x
\]

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 18). This calculation should be made in terms of the functional unit (see 6.1).

\[
WAOT_x = \sum_{i=1}^{n} \left( \frac{ED_x}{ILU_x} \right) \times OT_x
\]

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 19 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.

\[
LDS_x = WART_x \times WAOT_x
\]
**TABLE 11. Common ecosystem designations and restoration times**

<table>
<thead>
<tr>
<th>Existing Land Type</th>
<th>Agri_hi</th>
<th>Agri_li</th>
<th>Artificial_hi</th>
<th>Artificial_li</th>
<th>Forest_hi</th>
<th>Forest_li</th>
<th>Non-use</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Years)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agri_hi</td>
<td>0</td>
<td>10</td>
<td>0.5</td>
<td>2</td>
<td>25</td>
<td>50</td>
<td>500</td>
</tr>
<tr>
<td>Agri_li</td>
<td>0.5</td>
<td>0</td>
<td>0.5</td>
<td>2</td>
<td>25</td>
<td>50</td>
<td>500</td>
</tr>
<tr>
<td>Artificial_hi</td>
<td>5</td>
<td>10</td>
<td>0</td>
<td>2</td>
<td>25</td>
<td>50</td>
<td>500</td>
</tr>
<tr>
<td>Artificial_li</td>
<td>2</td>
<td>5</td>
<td>0.5</td>
<td>0</td>
<td>25</td>
<td>50</td>
<td>500</td>
</tr>
<tr>
<td>Forest_hi</td>
<td>1</td>
<td>2</td>
<td>0.5</td>
<td>2</td>
<td>0</td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td>Forest_li</td>
<td>1</td>
<td>2</td>
<td>0.5</td>
<td>2</td>
<td>10</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Non-use</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>2</td>
<td>10</td>
<td>25</td>
<td>0</td>
</tr>
</tbody>
</table>

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 Comparing Alternatives. The methodology in 6.5 provides relative scores for each impact category for each alternative evaluated. The following sections describe an effective decision analysis method for comparing alternatives with respect to sustainability.

6.6.1 Normalizing Impact Scores. Impact category results generated from the use of scoring factors are recorded in different units of measure and are incomparable. To alleviate this common challenge, it is recommended that evaluators normalize SLCA results so that alternatives can be compared across impact categories. *The SLCA tool referenced in 6.5.1 automatically calculates SLCA results, normalizes the results, and generates graphical displays of the data (see 6.6.2).* However, if evaluators choose to conduct the assessment manually, guidance is provided below for normalizing the SLCA results and generating graphical displays of those results.

The results of the impact assessment under the guidance of 6.5 can be used to assign normalized scores (\(N_{S_x}\)) 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 methodology, the worst performer will be assigned a normalized score of 100% and represents the outermost parameter of the scale against which all other alternatives will be assessed. \(N_{S_x}\) for all alternatives not considered worst is calculated as the difference between the worst performing score (\(A_{\text{worst}}\)) and Alternative X’s score (\(A_x\)), subtracted from the number one and divided by the worst performer’s score (see Equation 20). This value is then converted into a percentage by multiplying by 100.

\[
N_{S_x} = \left[1 - \frac{A_{\text{worst}} - A_x}{A_{\text{worst}}} \right] \times 100
\]

It is important to note that when comparing alternatives, larger impacts indicate less desirable alternatives and result in larger overall sustainability footprints. This implies that alternatives with relatively smaller impact footprints (smaller normalized scores) are considered more sustainable, and are thus preferred.
6.6.2 Creating a Spider Web Diagram. Once a normalized score is assigned to each alternative within each impact category, evaluators can present these dimensionless scores in a spider web, or radar, diagram (see FIGURE 12) to compare alternatives across impact categories. The spider web diagram provides a visual means of comparing alternatives based on their sustainability impacts, normalized on a comparable scale of 0% to 100%. Each “spoke” of the diagram represents one of the 17 impact categories. Impact category results for each alternative are then plotted on the 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 (i.e., the smallest footprint). 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 identify impacts with large differences between evaluated alternatives to discern tradeoffs in impact categories for a single system as well as tradeoffs among multiple systems.

NOTE: The SLCA tool presented in 6.5.1 automatically generates the spider web diagram displayed in FIGURE 12.

FIGURE 12. Example spider web chart
Once all alternatives are graphed on a spider web diagram, evaluators can reduce the number of acceptable alternatives by eliminating those that have the largest impact footprint. In FIGURE 12, Alternative 2 has the smallest footprint for most impact categories and is more likely to be the most sustainable materiel solution. However, most scenarios will not be as obvious and will require tradeoffs across impact categories. Evaluators should determine, and provide justification for the methodology used for making such trades and eliminating alternatives.

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

Evaluators should note that using the spider web diagram reduction methodology is less subjective than using weighted scoring methodologies because the results do not rely on previously determined priorities that: (1) depend on stakeholder consensus; and (2) can alter the results of the analysis. However, this method is still subjective in that decision makers must decide on which impact categories should take priority when tradeoffs are needed post analysis. Still, interjecting stakeholder bias post analysis provides for a more efficient analysis of alternatives, as these results can be used to better focus tradeoff discussions (e.g., land degradation, water loss and global warming highlighted in FIGURE 12). By reducing subjectivity and user bias, the characterization of impacts resulting from this methodology are more justifiable.

6.6.4 Detailed Design. Evaluators can also use results from the spider web diagram to inform the design of systems, sub-systems, or components. Results can be generated for different design options enabling evaluators to compare the impacts of design choices. Furthermore, by analyzing the resource requirements identified with corresponding mission, human health and environmental impacts, evaluators can identify resource requirements that are driving the most significant impacts. This information can be an important element in design decisions by supporting the principles of sustainable design (see 4.2.1) and by informing life cycle cost estimates.

7. DOCUMENTING THE 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. INTEGRATING SUSTAINABILITY ANALYSES INTO ACQUISITION

Sustainability Analyses in Acquisition Phases. Sustainability Analyses, as discussed in Section 4.3 of the Defense Acquisition Guide, 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.

As part of a system’s life cycle management, a Sustainability Analysis can be completed during a number of the phases set forth in the Defense Acquisition Management System. These phases include: (1) Pre-Systems Acquisition (from the Materiel Development Decision to Milestone B); (2) Systems Acquisition (from Milestone B to the Full-Rate Production (FRP) Decision Review); and (3) Sustainment (from the FRP Decision review to the end of the system’s service life).\(^{15}\) To have the greatest influence on system design, Sustainability Analyses should, at the very least, be conducted during Technology Development and Preliminary Design (pre-Milestone B). It is also recommended that Sustainability Analyses be updated when more refined data become available after Milestone B (e.g., sustainment and end-of-life activities), and used to inform similar systems in earlier phases of acquisition (see FIGURE 13). 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). The following paragraphs discuss sustainability-related activities during the three periods of defense acquisition.

a. Pre-Systems Acquisition. During this period, the capabilities and major constraints (e.g., cost, schedule, performance, and available technology) are established to frame the acquisition strategy and program structure for both the system and its support. This period includes the Materiel Solution Analysis Phase and the Technology Development Phase. Sustainability Analyses conducted during this period evaluate the resources required by each materiel solution.

\(^{15}\) DoD Instruction 5000.02, December 8, 2008. Enclosure 2.
Generally, the Sustainability Analysis should start at the system level but can selectively occur at lower levels of indenure (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.

In the Materiel Solution Analysis phase, the Analysis of Alternatives (AoA)\textsuperscript{16} represents the first opportunity for sustainability to be considered in materiel solutions. The AoA Study Guidance and the resulting AoA should be informed by a Sustainability Analysis when appropriate, and updated accordingly as both documents evolve during the acquisition process. As the foreword to this guide indicates, sustainability involves the wise use of resources, which includes financial resources, throughout the entire life cycle. \textit{A suggested method for analyzing costs associated with a Sustainability Analysis is under development and will be added at a later date to this guide.}

Another opportunity to assess sustainability occurs with the development of the draft Technology Development Strategy (TDS). The TDS provides for specific cost, schedule and performance goals, including exit criteria for the Technology Development phase. Appropriate sustainability requirements can be introduced as part of the TDS.

If the Milestone Decision Authority elects, the program will proceed into the Technology Development phase. In this phase, at least two competing teams will produce prototypes to reduce technical risk, validate designs and cost estimates, and refine requirements. If appropriate, sustainability requirements can be included in the Request for Proposals issued to industry for subsequent evaluation by the Source Selection Evaluation Board. The Preliminary Design Review (PDR) is the primary systems engineering activity that takes place during the Pre-Systems Acquisition period. The PDR can be informed by Sustainability Analyses as well. The PDR should demonstrate how principles of sustainable design (see 4.2.1) were incorporated into the system in preparation for Milestone B approval.

b. \textbf{Systems Acquisition}. The Systems Acquisition period consists of designing, producing, and deploying the equipment and its support system. This period includes the, Engineering and Manufacturing Development (EMD) phase (from Milestone B to Milestone C), and the Production and Deployment phase (from Milestone C to the Full Rate Production Decision review). During the EMD phase, Sustainability Analyses 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. Significant activities include:

1) Using the systems engineering process to design a more sustainable system and supply requirements; and

\textsuperscript{16}The results of the Sustainability Analysis should, if appropriate, be reported in all formally commissioned AoA’s. DoDI 5000.02 identifies the statutory requirements for AoA’s and the AoA procedural responsibilities; the process is further detailed in the Defense Acquisition Guidebook.
2) Testing to verify that the total system requirements have been achieved and in a manner that minimizes resource consumption, 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 Critical Design Review (CDR) is the primary development activity that takes place during the Systems Acquisition period. The CDR can be informed by Sustainability Analyses and demonstrate how principles of sustainable design (see 4.2.1) were incorporated into the system in preparation for Milestone C approval. The AoA (updated as necessary after Milestone B) should document the chosen system’s refined Sustainability Analysis.

c. Sustainment. Sustainment activities execute a support program that meets readiness and operational support performance requirements. Sustainability Analyses should inform the Life Cycle Sustainment Plan. Specifically, the Sustainability Analysis should inform the level of a program’s achieved effectiveness by:

1) Analyzing the impact of proposed sustainability-related design 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\(^\text{17}\); and
   c) Identify and analyze readiness risk areas, as well as 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.

\(^{17}\)In some cases, an increase within a specific system may be significantly offset by a major saving elsewhere within the DoD. Consequently, it may be beneficial to involve higher level organizations in these decisions.
APPENDIX B. SLCA SCORING FACTORS FOR ALL RESOURCE INPUTS

See Appendix B Excel File

APPENDIX C. BEST-PRACTICE RESOURCES FOR IDENTIFYING NON-HAZARDOUS, SUSTAINABLE CHEMICAL AND MATERIAL ALTERNATIVES
<table>
<thead>
<tr>
<th>Institution</th>
<th>Reference</th>
<th>Document Description</th>
<th>Info Type*</th>
</tr>
</thead>
</table>

*EVALUATION CRITERIA (EC); FRAMEWORK(S) (F); PRINCIPLES (Po); PROTOCOL(S) (Po); METHOD(S) (Me); MODEL(S) (Mo); TOOL(S) (T)
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 LCI 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 LCI 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) 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). 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.** 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 LCI 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 LCI 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). 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 E. EXAMPLE LIFE CYCLE ACTIVITY PROFILE (GENERIC AIRCRAFT)

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Life Cycle Phases</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Raw Materials Acquisition</td>
</tr>
<tr>
<td>Energy</td>
<td>• Mining of minerals &amp; fuel</td>
</tr>
<tr>
<td></td>
<td>• Refining of Fuel</td>
</tr>
<tr>
<td>Water</td>
<td>• Mining of minerals &amp; fuel</td>
</tr>
<tr>
<td></td>
<td>• Refining of Fuel</td>
</tr>
<tr>
<td>Chemicals &amp; Materials</td>
<td>• N/A</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Land Use</td>
<td>• Mining of minerals &amp; fuel</td>
</tr>
<tr>
<td></td>
<td>• Refining of Fuel</td>
</tr>
</tbody>
</table>

### Legend

- Minimal to No Impact
- Low Impact
- Medium Impact
- High Impact
APPENDIX F. CHARACTERIZATION FACTORS

<table>
<thead>
<tr>
<th>Impact Category</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Source Reliability</td>
<td>Energy Source Reliability is a score calculated by the user for each specific type of energy carrier. These scores are determined in the &quot;Input - Energy&quot; tab. No characterization factors are needed for converting inputs to impact potential.</td>
</tr>
<tr>
<td>Chemical and Material Availability</td>
<td>Chemical and Material Availability is a score calculated by the user for each chemical or material input. These scores are determined in the &quot;Input - C&amp;M&quot; tab. No characterization factors are needed for converting inputs to impact potential.</td>
</tr>
<tr>
<td>Chemical and Material Recovery</td>
<td>Chemical and Material Recovery is a score calculated by the user for each chemical or material input. These scores are determined in the &quot;Input - C&amp;M&quot; tab. No characterization factors are needed for converting inputs to impact potential.</td>
</tr>
<tr>
<td>Total Water Use</td>
<td>Total Water Use is a score calculated by the user in accordance with the amount of water consumed. These scores are determined in the &quot;Input - Water&quot; tab. No characterization factors are needed for converting inputs to impact potential.</td>
</tr>
<tr>
<td>Global Warming</td>
<td>Global Warming 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 <a href="http://www.epa.gov/nrmrl/std/traci/traci.html">http://www.epa.gov/nrmrl/std/traci/traci.html</a></td>
</tr>
<tr>
<td>Ozone Depletion</td>
<td>Ozone Depletion 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 <a href="http://www.epa.gov/nrmrl/std/traci/traci.html">http://www.epa.gov/nrmrl/std/traci/traci.html</a></td>
</tr>
<tr>
<td>Smog Formation</td>
<td>Smog Formation 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 <a href="http://www.epa.gov/nrmrl/std/traci/traci.html">http://www.epa.gov/nrmrl/std/traci/traci.html</a></td>
</tr>
<tr>
<td>Water Loss</td>
<td>Water Loss is an efficiency score calculated by the user in accordance with the type and amount of water consumed. These scores are determined in the &quot;Input - Water&quot; tab. No characterization factors are needed for converting inputs to impact potential.</td>
</tr>
<tr>
<td>Water Scarcity</td>
<td>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 &quot;Input - Water&quot; tab. No characterization factors are needed for converting inputs to impact potential.</td>
</tr>
<tr>
<td>Water Degradation</td>
<td>Water Degradation is a score calculated by the user in accordance with the type and amount of water consumed. These scores are determined in the &quot;Input - Water&quot; tab. No characterization factors are needed for converting inputs to impact potential.</td>
</tr>
<tr>
<td>Impact Category</td>
<td>References</td>
</tr>
<tr>
<td>-----------------</td>
<td>------------</td>
</tr>
<tr>
<td><strong>Human Toxicity</strong></td>
<td>Human Cancer Toxicity characterization factors are from the USEtox™ model. For human health characterization, cancer and non-cancer factors were aggregated into a single metric. 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 media. 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™ 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™ characterization factors are available from <a href="http://www.usetox.org/">http://www.usetox.org/</a>. For more information about the USEtox™ 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.</td>
</tr>
<tr>
<td><strong>Respiratory Effects</strong></td>
<td>Respiratory Effects 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 <a href="http://www.epa.gov/nrmrl/std/traci/traci.html">http://www.epa.gov/nrmrl/std/traci/traci.html</a></td>
</tr>
<tr>
<td><strong>Ecotoxicity</strong></td>
<td>Ecotoxicity characterization factors are from the USEtox™ model and determined using estimates to freshwater impact. 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 media. 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™ 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™ characterization factors are available from <a href="http://www.usetox.org/">http://www.usetox.org/</a>. For more information about the USEtox™ 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.</td>
</tr>
<tr>
<td><strong>Human Noise</strong></td>
<td>Human Noise is a score calculated by the user in accordance with the amount of noise output, per affected population, resulting from the system being evaluated. These scores are determined in the &quot;Input - Noise&quot; tab. No characterization factors are needed for converting such data to impact potential.</td>
</tr>
<tr>
<td><strong>Ecosystem Noise</strong></td>
<td>Ecosystem Noise is a score calculated by the user in accordance with the amount of noise output, per affected population, resulting from the system being evaluated. These scores are determined in the &quot;Input - Noise&quot; tab. No characterization factors are needed for converting such data to impact potential.</td>
</tr>
</tbody>
</table>