Department of Defense Guidance

Sustainability Analysis Guidance:

Integrating Sustainability into Acquisition Using Life Cycle Assessment

Version 7.0

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Preface

Weapon system managers and product support managers can require a Sustainability Analysis during any phase of the Defense Acquisition System to help compare the total life cycle costs (LCCs) and environmental footprint or impact of design alternatives. Acquisition activities can be supported by a Sustainability Analysis include analysis of alternatives (AoA), trade space analysis, Business Case Analysis (BCA), preliminary design, supportability analysis, and detailed design. The Sustainability Analysis includes traditional Department of Defense (DoD) "internal" costs in addition to often-overlooked "external" and "contingent" costs. A more comprehensive understanding of cost, as well as the environmental impacts of design decisions, will help move the DoD towards improved both mission readiness and affordability, as outlined in the 2018 National Defense Strategy (NDS). Life cycle approaches are critical to these goals. First, LCA helps prevent liability shifting, so that one mission activity does not impede another (e.g., in another location or in the future). Secondly, SA-based LCC helps to fully identify costs. These costs can be associated with operations and support (which often account for the majority of a system's total cost and often are not fully accounted for in DoD cost estimates (CAPE, 2014)), or with future liability costs that are traditionally overlooked entirely.

This document provides guidance for combining LCC estimating with Life Cycle Assessment (LCA) to conduct a Sustainability Analysis in accordance with Chapter 3 Section 2.4.3 of the Defense Acquisition Guidebook.[1]

To ensure transparency, this guidance provides a full description of the underlying Sustainability Analysis framework. It builds on existing LCC and LCA standards and guidance, referenced throughout this document. Tools, example Sustainability Analyses, and other resources will be made available on the DoD environment, safety, and occupational health (ESOH) in Acquisition website.[2]

All comments (recommendations, additions, and deletions) and any pertinent, beneficial document information may be addressed to Office of the Assistant Secretary of Defense (Sustainment), ODASD (Environment), via e-mail to osd.pentagon.ousd-atl.mbx.cmrmp@mail.mil.

[1] https://www.dau.mil/tools/dag
[2] http://www.denix.osd.mil/esohacq/

Revision History

The current guidance is the latest in a sequence of documents that have been updated since revision 1.0 was released in October 2012. The table below provides descriptions of earlier versions of this document through the current version.

Revision Number	Date	Title or Brief Description
1.0	Oct 2012	Streamlined Life Cycle Assessment Process for Evaluating Sustainability in DoD Acquisitions
1.1	Mar 2013	Streamlined Life Cycle Assessment Process for Evaluating Sustainability in DoD Acquisitions
1.2	Oct 2013	Streamlined Life Cycle Assessment Process for Evaluating Sustainability in DoD Acquisitions
2.0	May 2014	Integrating Sustainability into DoD Acquisitions
3.0	Mar 2015	Integrating Sustainability into DoD Acquisitions
4.0	Jul 2016	Integrating Sustainability into DoD Acquisitions
5.0	Dec 2016	Sustainability Analysis Guidance: Integrating Sustainability into Acquisition Using Life Cycle Assessment
6.0	Jul 2019	Sustainability Analysis Guidance: Integrating Sustainability into Acquisition Using Life Cycle Assessment
7.0	June 2020	Sustainability Analysis Guidance: Integrating Sustainability into Acquisition Using Life Cycle Assessment

Executive Summary

This guidance document presents a standardized framework for conducting a Sustainability Analysis, an assessment of costs (quantified using life cycle costing, LCC) and potential environmental liabilities (quantified using life cycle assessment, LCA) for DoD weapons systems, equipment, or platforms. LCC quantifies the cost to the government of a system over its useful life, including research and development, testing, production, operations, maintenance, and disposal. LCA quantifies resource requirements, environmental releases, and waste through each life cycle stage of a product or system and estimates the associated impacts on human health and ecosystems. LCA provides a framework in which it is possible to identify future liabilities, such as that posed by per- and polyfluoroalkyl substances (PFAS) compounds. The Sustainability Analysis approach fills gaps in current requirements, described in Section 1.2, by providing the following:

- A structured systems framework, using both LCA and LCC for evaluating design alternatives: current requirements call for such analyses but do not provide a framework to execute the analyses.
- A more comprehensive approach to LCC: current guidance does not fully address procedures to evaluate costs associated with resource requirements, environmental releases, and waste through each life cycle stage of a system.

Sustainability Analysis, by combining comprehensive cost and environmental aspects of designs, will help move the DoD towards improving both mission readiness, affordability, and sustainability as outlined in the 2018 NDS. Sustainability Analysis reveals and estimates three types of sustainability-related costs, described below. While internal costs are typically captured in Acquisition processes, external and contingent costs are typically overlooked. External costs are captured using LCA, and contingent costs are captured using life cycle approaches and probabilistic valuation.

- **Internal costs** are realized by the DoD during the lifetime of the system. Such costs can be classified as direct or indirect. Direct costs are those costs that are traditionally considered in a life cycle costing exercise. Indirect costs are overhead costs that are typically tracked at a facility level and not allocated to a particular system. Decisions made in early acquisition phases, such as design decision or material and chemical selection, can impact sustainability-related costs realized in later acquisition phases. Examples include investments in personal protective equipment (PPE) and engineering controls, hazardous waste management, wastewater treatment, permitting, environmental or hazardous differential pay, and personnel medical monitoring. This guidance outlines a process for explicitly quantifying internal costs so they can be integrated into LCC estimates.
- **External costs** are realized by society or organizations outside of DoD. During a system's life cycle, resources are used, pollutants are released, and waste is generated. These releases may degrade human health, ecosystem quality, or resource availability, they may contribute to climate change. This guidance outlines a process for using LCA to estimate life cycle impacts to resource availability, climate change, human health, and ecosystem quality, and monetizing those impacts so that they can be considered in parallel with LCC estimates.
- **Contingent costs** occur in the future as a result of decisions made today or as a result of future events (e.g., litigation, site remediation, hospitalization, disability, increased cost, or unavailability of resources). If realized, these costs would result in additional internal costs to the DoD. For example, a hazardous material could be restricted due to future regulatory actions, resulting in

additional costs to qualify and implement a replacement substance. This guidance outlines a process for uncovering contingent costs that may occur in the future in the absence of risk mitigation.

The DoD Sustainability Analysis framework is founded on existing guidelines and standards, including the ISO 14040 (ISO, 2006) LCA standards and existing DoD LCC guidance. It was tailored to integrate with existing DoD-required analyses and leverages available LCA data and models to reduce data collection requirements, striking a balance between accuracy and level of effort. This guidance describes five steps that are instrumental to, and in support of, existing cost and performance analyses.

- **STEP 1: Define the Scope of the Analysis**. The first step is to clearly define the objectives and range of the study. This includes a description of required performance, specific alternatives analyzed, and the life cycle stages included in the Sustainability Analysis. A well-defined scope ensures that all alternatives considered fulfill all performance requirements and are compared on an equivalent basis.
- **STEP 2: Develop a Life Cycle Inventory**. The second step is to identify and quantify all relevant system inputs (e.g., resources, transportation, procured items and services), outputs (e.g., products, systems, or environmental releases), and internal DoD costs that fall within the scope of the analysis, and to develop an initial LCC estimate based on the internal DoD costs.
- **STEP 3: Estimate LCCs**. The fourth step is to estimate internal costs incurred by the DoD, external costs to society, and contingent costs that may be incurred by the DoD from future events over the system's life cycle.
- **STEP 4: Estimate Life Cycle Impacts**. The third step is to translate the inventory of inputs and outputs into impacts on resource availability, climate change, human health, and ecosystem quality. This is accomplished using a set of peer-reviewed, publicly available, impact assessment models.
- **STEP 5: Synthesize Results**. The fifth step is to analyze, interpret, and act on results to assess the level of confidence in the results, identify the life cycle activities that drive life cycle impacts and costs, and compare the performance of alternatives. If the comparison needs further data or definition, previous steps are repeated as necessary.

The Sustainability Analysis is an "overlay" on performance—it identifies the most sustainable alternative among those that meet performance requirements, as defined by the Initial Capabilities Document (ICD), the Capability Development Document (CDD), or performance specifications. It supports multiple government policies and initiatives, including DoD Directive 5000.01, Executive Order (EO) 13834, DoD Instruction 5000.2, Military Standard 882E, DoD Instruction 5000.73, and the Better Buying Power Initiative (these policies and initiatives are briefly described in Section 1.2). The data required for these other initiatives and analyses can often be used in the Sustainability Analysis, resulting in limited duplication of data collection efforts. The results of a Sustainability Analysis can help acquisition officials, including weapon system managers and product support managers, make more informed design, logistics, and sustainment decisions towards meeting the goals put forth the above-mentioned policies and initiatives.

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Acronyms and Abbreviations

Acronym or Abbreviation	Meaning
AAF	Adaptive Acquisition Framework
AoA	Analysis of Alternatives
BCA	Business Case Analysis
BLS	Bureau of Labor Statistics
CAPE	Cost Assessment and Program Evaluation
CDD	Capability Development Document
CO2	Carbon Dioxide
DAG	Defense Acquisition Guidebook
DALY	Disability Adjusted Life Year
DIO	Defense Input-Output
DoD	U.S. Department of Defense
DoDD	Department of Defense Directive
DoDI	Department of Defense Instruction
EEIO	Environmentally Extended Input-Output
EMD	Engineering and Manufacturing Development
EO	Executive Order
ESOH	Environment, Safety, and Occupational Health
GAO	General Accountability Office
ICD	Initial Capabilities Document
I-O	Input–Output
IPS	Integrated Product Support
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LCSP	Life Cycle Sustainment Plan
MIL-STD	Military Standard
MOOTW	Military Operations Other Than War
NAICS	North American Industry Classification System
NDS	National Defense Strategy
O&S	Operations and Support
OMB	Office of Management and Budget
OEM	Original Equipment Manufacturer
P&D	Production & Deployment
PESHE	Programmatic Environment, Safety and Occupational Health Evaluation
PPE	Personal Protective Equipment
PPI	Producer Price Index
R&D	Research and Development
SE	Systems Engineering
TMRR	Technology Maturation and Risk Reduction
TOC	Total Ownership Cost

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1 Introduction

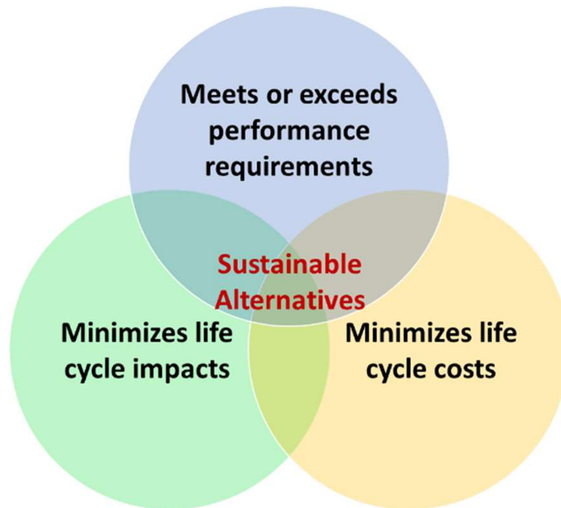

Figure 1. Key Elements of Sustainable Alternatives

The U.S. Department of Defense (DoD) acquires weapons, equipment, facilities, and platforms (hereafter referred to as "systems") that have life cycles of 30 years or more. To reduce the life cycle cost (LCC) and life cycle environmental, safety, and occupational health impacts of a system, acquisition personnel must fully understand costs and impacts that occur across each life cycle stage. Otherwise, they could inadvertently shift costs and/or liabilities to the DoD operational, logistics, and installations management communities (CAPE, 2014). As shown in Figure 1, a sustainable alternative for DoD meets all performance requirements outlined in the ICD, CDD, or component performance specifications; has a lower total ownership cost (TOC); and reduces costs and potential occupational or environmental liabilities ("impacts" in Figure 1).

The NDS calls for reform in the DoD to improve both mission readiness, affordability, and sustainability. Life cycle approaches are critical to these goals. First, LCA helps prevent liability shifting, so that one mission activity does not impede another (e.g., in another location or in the future). Secondly, SA-based LCC helps to fully identify costs. These costs can be associated with operations and support (which often account for the majority of a system's total cost and time in service (Figure 2), and these costs are often not fully accounted for in DoD cost estimates (CAPE, 2014)), or with future liability costs that are traditionally overlooked entirely. The importance of LCCs has been recognized by the Services such as the Army *Installations, Energy and Environment Strategy 2025* that has an objective to "Ensure that resource considerations, including sustainability, security, integrated design, and total life-cycle cost, are incorporated into plans, business processes, materiel management, and acquisition strategies at all levels" (ASA (IE&E), 2017). The Defense Acquisition Guidebook (DAG) recommends a life cycle approach (Sustainability Analysis Guidance [OASD, 2016]) for analyzing military systems and platforms. The Sustainability Analysis Guide emphasizes the importance of life cycle assessment (LCA) as an overlay to performance: systems are chosen to meet mission needs, and LCA provides insight into long-term costs and other liabilities, helping DoD to choose more cost-efficient systems.

Therefore, in the context of the DoD acquisition process, sustainability means wisely using resources to meet performance requirements while minimizing cost and potential occupational or environmental liabilities. "Sustainability" differs from "sustainment" in that it relates to the use of resources, and the associated impacts and costs over the system's life cycle. In contrast, sustainment is more concerned with the end user's ability to operate and maintain a system once it is in inventory and deployed. Acquisition and logistics professionals and engineers use the term "sustainment" to describe the support needed to operate and maintain a system over its lifetime. In contrast, "sustainability" requires consideration of all phases of a system's life cycle, including system design, development, production, operations, *sustainment*, and disposal.

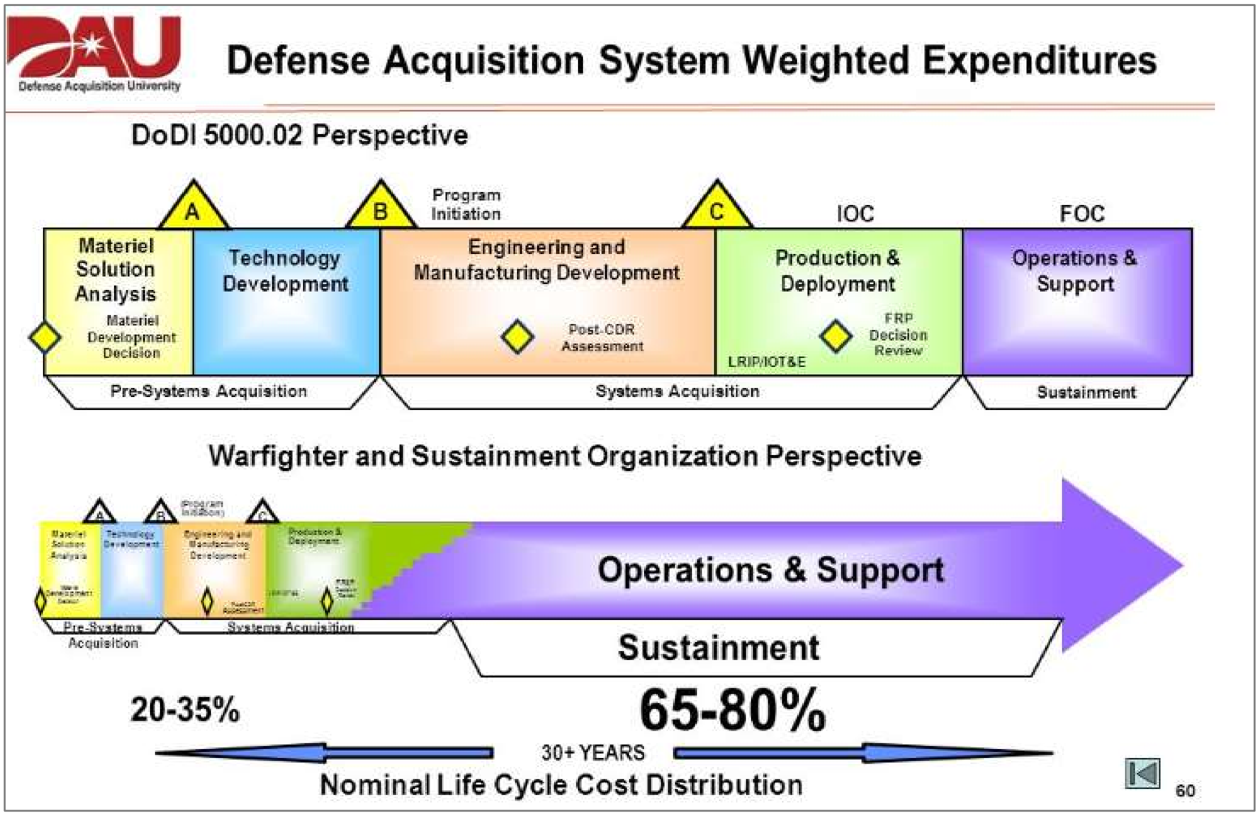

Figure 2. Defense Acquisition University (DAU) expenditures across the life cycle show that operations and support (sustainment) may account for the majority of total costs and time in service. Life cycle approaches, such as the OASD Sustainability Analysis Guidance (OASD, 2016), help researchers and program managers understand and control total costs.

The Defense Acquisition System is the management process by which the DoD provides effective, affordable, and timely systems to users. The acquisition process, described in DODI 5000.02[3] and discussed in Section 1.3 of this document, consists of five phases: material solution analysis (MSA), technology maturation and risk reduction (TMRR), engineering and manufacturing developmental (EMD), production and deployment (P&D), operations and sustainment, and disposal. Acquisition programs use LCC estimates, TOC estimates (DoDD 5000.01[4]), and environment, safety, and occupational health (ESOH) analyses to identify program risks and inform system trade-off analyses and key milestone decisions. However, current cost and ESOH analyses may be limited in scope and conducted independently. In contrast, Sustainability Analysis combines cost, liability, and ESOH analyses in a single framework. Furthermore, the Sustainability Analysis can use data required for other acquisition analyses, thus limiting duplication of data collection efforts and resulting in new insights from existing data.

Without a full life cycle understanding, significant impacts and future costs may be unintentionally locked in during system development and design and later incurred by the operations, logistics, and sustainment

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[3] https://shortcut.dau.mil/DODPUBS/5k2
[4] https://shortcut.dau.mil/DODPUBS/5k1

Sustainability Analysis provides a method to address gaps identified by CAPE:

"Choices in energy sources or chemicals and materials can have a significant impact on human health and the environment, leading to unintended consequences for the logistics, installations, and operational communities with associated increases to program life-cycle cost... These design features should be evaluated for life-cycle cost impacts where it is possible to do so. However, the current tools, methods, and data sources to evaluate the cost effects associated with many of these design features are quite limited and are areas for future research." – *Operating and Support Cost Estimating Guide* (CAPE, 2014).

communities. The direct financial costs associated with designing, producing, and deploying a system, including the financial costs associated with establishing operations and support (O&S) systems, are generally included in acquisition cost estimates. Indirect financial costs, such as overhead costs tracked at a facility level, are traditionally not allocated to a particular system's cost estimate. In addition, decisions made across the acquisition process determine the resources (e.g., energy, water, chemicals, and materials) needed to manufacture, operate, and sustain systems, as well as the resulting environmental releases and waste generation. The impacts of a system's life cycle on human health and the environment are also generally overlooked. In the SA framework, these impacts represent potential future liabilities to DoD.

1.1 Purpose

Sustainability Analysis combines LCC and LCA to compare two or more products or systems that meet the same performance requirements. Sustainability Analysis, therefore, provides insight into systems that achieve mission-centric performance requirements; it does not replace performance requirements, nor does it replace the Business Case Analysis (BCA) (US DoD, 2011). LCC quantifies the financial costs incurred by the DoD over a system's useful life, including research and development, testing, production, operations, maintenance, and disposal. External costs are captured using LCA, and contingent costs are captured using life cycle approaches and probabilistic valuation:

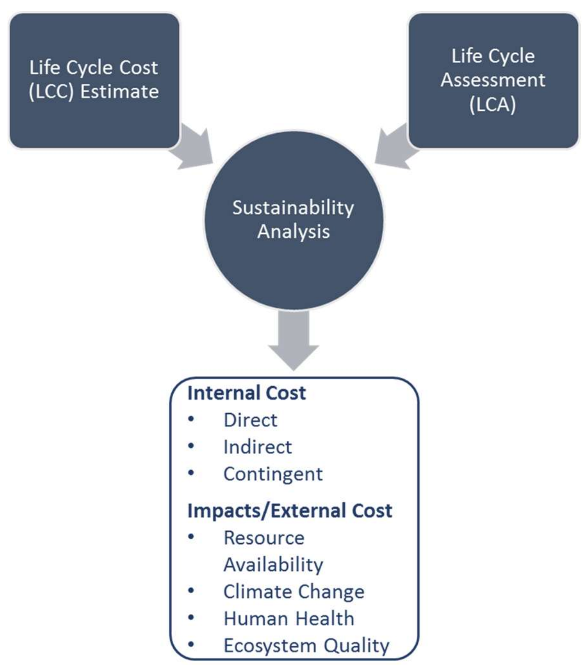

Figure 3. Sustainability Analysis evaluates the impact of design and sustainment decisions on total cost and occupational or environmental liabilities

- **Internal costs** are realized by the DoD during the lifetime of the system. Such costs can be classified as **direct** or **indirect**. **Direct** costs are those costs that are traditionally considered in a life cycle costing exercise. **Indirect** costs are overhead costs that are typically tracked at a facility level and not allocated to a particular system. Decisions made in early acquisition phases, such as design decision or material and chemical selection, can impact sustainability-related costs realized in later acquisition phases. Examples include investments in personal protective equipment (PPE) and engineering controls, hazardous waste management, wastewater treatment, permitting, environmental or hazardous differential pay, and personnel medical monitoring. This guidance outlines a process for explicitly quantifying internal costs, both direct and indirect, so they can be integrated into LCC estimates.

- **Contingent costs** occur in the future as a result of decisions made today or as a result of future events (e.g., litigation, site remediation, hospitalization, disability, increased cost, or unavailability of resources). If realized, these costs would result in additional internal costs to the DoD. For example, a hazardous material could be restricted due to future regulatory actions, resulting in additional costs to qualify and implement a replacement substance. This guidance outlines a process for uncovering contingent costs that may occur in the future in the absence of risk mitigation.
- **External costs** are realized by society or organizations outside of DoD. During a system's life cycle, resources are used, pollutants are released, and waste is generated. LCA provides the structure to quantify these impacts to human health, ecosystem quality, future resource availability, and the climate. These impacts are indicative of potential occupational and environmental liabilities and are monetized to make them more intuitive. Because these costs are not borne by DoD, they should not be added to the internal or contingent costs.

Figure 4 illustrates sustainability-related costs from using a hazardous material in a system, providing concrete examples of the costs discussed above. In addition to the costs associated with procuring and using the material in the system, internal costs may also include investments in PPE, hazardous waste management, and other internal risk management costs. External costs include damage to human health and ecosystem quality from exposure to hazardous materials released to the environment. Contingent costs may include cleanup of environmental pollution, medical cost for exposed DoD personnel, and substitute development and testing.

Internal Direct Costs	Internal Indirect Costs	External Costs	Contingent Costs
• Procurement of raw materials or reagents • System manufacturing	• Protective equipment • Utilities • Waste management	• Damage to human health • Damage to ecosystem quality	• DoD medical costs • Cleanup of pollution

Figure 4. Example Sustainability-Related Costs from Using Hazardous Materials in a System

Integrating LCA with LCC will relate sustainability impacts and associated costs to activities that cause them, thereby revealing traditionally hidden costs. Assessing the relative importance of sustainability impacts will highlight potential future risks, liabilities, and contingent costs.

By looking at both internal costs to the DoD and external costs to society and the environment, acquisition decision-makers can make fully informed decisions. A Sustainability Analysis can be used to compare the overall sustainability of alternatives, including conceptual and design alternatives for new acquisition systems, block upgrades for legacy systems, and O&S alternatives for new and legacy systems. A Sustainability Analysis can identify tradeoffs between upfront investment in risk mitigation and contingent costs associated with future impacts. For example, upfront investments in PPE, control systems, or material substitutions can prevent potentially larger costs due to impacts on human health or ecosystem quality later in the life cycle. This will enable more robust trade-off analyses and more informed trade-off decisions, ultimately resulting in more sustainable systems and lower LCCs, and better positioning of the DoD to achieve sustainability goals and avoid future related risks.

"A Sustainability Analysis examines and compares various system attributes associated with energy, water, solid waste, chemicals, materials, and land use. Outputs include decision diagrams that compare alternatives according to their relative sustainability indicators and related costs. These diagrams can be used to develop system life-cycle cost estimates." – *Defense Acquisition Guidebook*, Chapter 4.3.19.2. Sustainability Analysis

1.2 Requirements

A Sustainability Analysis addresses the following DoD requirements.

- DoD Directive (DoDD) 5000.01, "The Defense Acquisition System," requires management of acquisition programs through a Systems Engineering (SE) approach that optimizes total system performance and minimizes TOC. It also requires identification of the major drivers of TOC.
- DoD Instruction (DoDI) 5000.2, "Operation of the Defense Acquisition System," requires that hazardous materials, wastes, and pollutants (e.g., discharges, emissions, noise) associated with a system be considered in ESOH analyses and documented in the Programmatic ESOH Evaluation (PESHE). A Sustainability Analysis can use information from the PESHE to inform risk mitigation strategies.
- Defense Acquisition Guidebook (DAG) section 4.3.19.2, "Sustainability Analysis," identifies Sustainability Analysis as a tool for assisting the Systems Engineer in designing more sustainable systems, and identifies acquisition activities that can be supported by a Sustainability Analysis, including analysis of alternatives (AoA), trade space analysis, BCA, preliminary design, supportability analysis, and detailed design.
- DAG section 4.3.18.9, "Environment, Safety, and Occupational Health," requires use of Sustainability Analysis for informing ESOH hazard analyses.
- DAG section 4.3.18.16, "Operational Energy," states that the results of the Sustainability Analysis can be used to inform energy analyses.
- The DoD Product Support BCA Guidebook provides a structure methodology for comparing alternatives by examining mission and business impacts (financial and non-financial), risks, and sensitivities. The guidebook identifies sustainability in both the benefits and risk sections, and states that "the PM must consider whether the project can balance economics (i.e., profit),

Sustainability Analysis will help acquisition program managers:

1. Identify hidden sustainability-related internal costs
2. Evaluate life cycle impacts and external costs
3. Identify potential future risks, liabilities, and contingent costs
4. Reduce DoD's total ownership costs (TOC)
5. Reduce external impacts and costs
6. Support achievement of DoD sustainability goals

efficiency, environment, safety, and social responsibility (i.e., impact on local community) in the long term."

- Executive Order (EO) 13834, "Efficient Federal Operations," directs federal agencies to reduce energy, water, and waste to meet statutory requirements as well as utilize sustainable acquisition and procurement practices.
- DoD's annual Sustainability Report and Implementation Plan reports progress towards achieving sustainability goals established by EO 13834. It also establishes a path for furthering DoD's sustainability goals, which includes lowering the TOC and acquiring more sustainable systems that use less energy, water, and toxic chemicals by considering life cycle impacts during acquisition.
- Military Standard (MIL-STD) 882E requires integration of a systematic approach for identifying, classifying, and mitigating hazards, including ESOH hazards during the acquisition SE process.
- DoDI 5000.73, "Cost Analysis Guidance and Procedures," requires realistic estimates of cost for DoD acquisition programs. A Sustainability Analysis can uncover heretofore hidden costs and inform required LCC estimates.
- The Better Buying Power Initiative requires the acquisition community to control costs throughout the product life cycle by understanding and controlling future costs from a program's inception.
- Materiel Reliability and Ownership Cost were identified by the Chairman of the Joint Chiefs of Staff Instruction (CJCSI) 3170.01F as two mandatory sustainment Key System Attributes (KSAs).

1.3 Applicability to the Defense Acquisition System

The Sustainability Analysis can be incorporated into all phases of the Defense Acquisition System. The Adaptive Acquisition Framework[5] (AAF) provides a series of pathways that are appropriate for different types of acquisitions. A key principle of the AAF is that acquisition delays occur when sustainment is not considered up-front. The Sustainability Analysis can be applied in a traditional acquisition (e.g., Major Capability Acquisition pathway) or applied in another pathway as part of the AAF. The Sustainability Analysis framework encourages analysts to consider sustainment, disposal, and ESOH liabilities, helping programs to avoid delays and unforeseen costs.

Traditionally, acquisition programs proceed through a series of milestone reviews and other decision points to assess a program's readiness to proceed to the next acquisition phase and to make sound investment decisions. LCC cost estimates are required for milestone reviews and other decision points. While sustainability-related costs incurred by DoD (e.g., energy for sustainment activities, water consumption, personnel medical monitoring, waste management and disposal, etc.) are generally locked in during early acquisition phases, they are often not fully accounted for in these cost estimates. The Sustainability Analysis presented in this guidance fills this gap, allowing for more robust and informed acquisition programs. The Sustainability Analysis is consistent, without duplication of data collection efforts, with other acquisition considerations such as operational energy, supportability, and ESOH. The data required for these other acquisition analyses can often be used in the Sustainability Analysis. Sustainability Analysis can be applied to inform this process at each of the five (5) acquisition system phases, as illustrated in Figure 5 and detailed below.

[5] https://aaf.dau.edu/

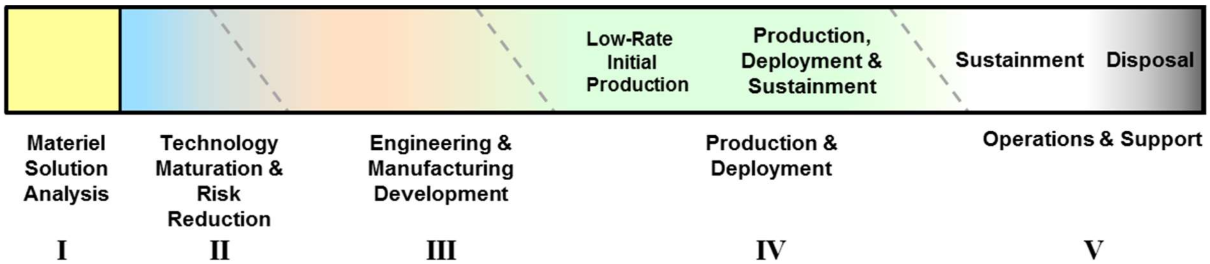

Figure 5. Five Phases within the Defense Acquisition System

I. The purpose of the **Material Solution Analysis (MSA)** phase is to choose the concept for the system, define system-specific requirements, and develop a system acquisition strategy. Within this phase, a Sustainability Analysis can support an Analysis of Alternatives by identifying important sustainability impacts of conceptual alternatives. Sustainability impacts can be incorporated as trades in trade space analyses. Analysis of the impact of sustainability attributes on LCC, TOC, human health, and the environment can inform affordability analysis and risk analysis, as well as planning for risk mitigation.

II. The purpose of **Technology Maturation & Risk Reduction (TMRR)** phase is to reduce technology, engineering, integration, and LCC risk to enable execution of a contract for system EMD. The Sustainability Analysis can be used to provide a deeper analysis of the actual sustainability-related costs and risks associated with the preliminary design and its sustainment. Integrating sustainability-related costs into cost estimates can equip systems engineering trade-off analyses to more fully show how cost varies as a function of major design parameters. These costs should be included when evaluating life cycle affordability as a factor in key technical risk areas. During Pre-Systems Acquisition, a Sustainability Analysis can identify potential environmental impacts and resulting indirect costs that may impact supportability and inform supportability analysis.

III. The purpose of the **Engineering and Manufacturing Development (EMD)** phase is to develop, build, and test a system, and to support production and deployment decisions. A Sustainability Analysis can be used during system design and to identify potential sustainability concerns to inform design reviews and design iterations. For example, a Sustainability Analysis at this phase might identify materials that pose significant risk to human health and ecosystem quality and can be designed out of the system. Information collected during developmental testing and evaluation can be used to update Sustainability Analysis assumptions. The Sustainability Analysis can also be used to identify potential manufacturing and sustainment risks related to environmental impact and the associated hidden cost. Sustainability Analysis can be used to inform specific design choices (e.g., material and component selection) and sustainment choices (e.g., selection of sustainment alternatives). Significant potential environmental impacts associated with sustainment should be documented in the product support package. During Systems Acquisition, Sustainability Analysis can be used to identify potential environmental impacts that may adversely impact deployed readiness and inform updated supportability analysis. For example, a Sustainability Analysis at this phase might identify need for PPE or other risk management requirements during system sustainment.

IV. The purpose of the **Production and Deployment (P&D)** phase is to produce, deliver, and field systems, including initiation of all system sustainment and support activities. Significant potential environmental impacts and the associated costs should be considered during the Full-Rate Production Decision or the Full Deployment Decision. The Sustainability Analysis should inform management efforts to identify opportunities for driving down sustainability-related risk and generating savings by reducing sustainability impact and associated costs. An example improvement might include investing in new materials that reduce out-year environmental impacts and environmental management costs.

V. The purpose of the **Operations and Support (O&S)** phase is to execute the product support strategy, ensure materiel readiness, provide operational support, sustain the system over its life cycle, and dispose of the system (to include disposal). Significant potential environmental impact and opportunities for improvement should be included in the Life Cycle Sustainment Plan (LCSP) (as required by DoD Instruction 5000.02). During O&S, system readiness will be monitored, efforts will be made to identify continuous improvement and cost reductions opportunities, and, when necessary, corrective actions will be implemented. Technological advances may introduce solutions for reducing significant potential environmental impact and associated costs. The Sustainability Analysis should be used to evaluate the potential environmental impacts and associated costs of alternatives (e.g., correction actions and new technologies), and inform a BCA of these alternatives. During sustainment, Sustainability Analysis should be used to evaluate the potential environmental impact and associated costs of adjustments to the sustainment program and inform updates to the Sustainability Analysis.

2 Overview and Scope of Sustainability Analysis

A Sustainability Analysis combines life cycle costing and life cycle environmental analysis to evaluate an alternative with respect to internal, contingent, and external costs. The Sustainability Analysis includes activities occurring throughout a system's life cycle (Figure 6). For the purpose of the Sustainability Analysis, these activities, as well as the associated impacts and costs, are specified as upstream or downstream. Assignment of activities as upstream and downstream depends on the perspective from which the Sustainability Analysis is being conducted, i.e., an organization's location in the supply chain.

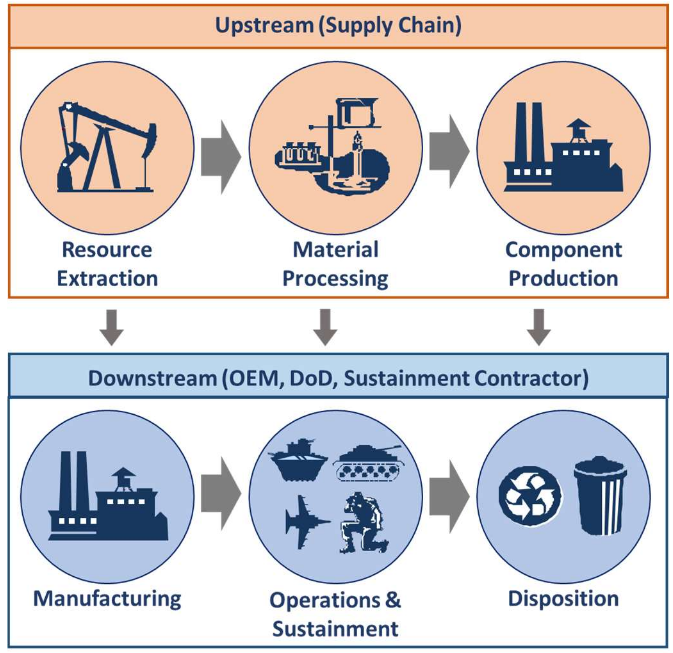

Figure 6. Upstream and Downstream Components of an Example System Life Cycle, as Defined from the Perspective of an OEM.

- **Upstream**: Activities occurring prior to the system being analyzed. In general, upstream includes the organization's supply chain, i.e., the production of goods (e.g., components, parts, chemicals, materials, electricity) and services (e.g., waste management, transportation) procured by the organization to complete its activities.
- **Downstream**: Includes activities conducted by the organization, as well as activities conducted in later life cycle stages. Depending on who is conducting the Sustainability Analysis, downstream may include the assembly, operation, sustainment, and disposal of the system. Downstream may also include procured products and services. For example, waste management is a procured service that will likely occur during many downstream activities.

Figure 6 illustrates the upstream and downstream activities for an original equipment manufacturer (OEM). In this case, it is assumed that the OEM procures components from their supply chain and assembles the larger system procured by the DoD, the DoD operates the system, a sustainment contractor maintains the system, and the DoD will dispose of the system at the end of its useful life. In this case, upstream includes activities related to extracting resources, processing materials, and producing materials and components used by the OEM to manufacture the system, the DoD to operate and dispose of the system, the sustainment contractor to maintain the system.

A Sustainability Analysis is an overlay to existing cost and performance analyses, such that SA provides a framework to differentiate among alternatives that meet performance requirements. As such, SA does not require significant additional data collection (i.e., beyond that required during acquisition milestones). This section describes the tools that are used in a Sustainability Analysis; the following sections describe their application.

2.1 Life Cycle Costing

LCC estimates the cost to the government of a system over its useful life, including research and development, testing, production, operations, maintenance, and disposal. LCC estimates conducted as part of a Sustainability Analysis should adhere to established DoD and relevant federal cost estimating policies, instructions, and guidance. For better integration into existing analyses, sustainability-related costs should be assigned to standard DoD cost element structures customarily used in LCC estimation.

2.1.1 DoD Life Cycle Cost Guidance

DoD 5000.4-M sets forth authoritative guidance on developing LCC estimates for DoD systems. The manual focuses on procedures to follow when preparing estimates to support milestone decision reviews. However, the cost structure described in that manual also applies to other analyses, such as those used to support AoAs, BCAs, Sustainability Analyses, and LCSPs. The Defense Acquisition Guidebook describes the boundary of an LCC analysis as consisting of all elements directly associated with the system (acquisition program) plus other indirect costs that are "logically attributed to the program." In summary, this boundary should include the total cost to the taxpayer that can be traced to a system alternative being assessed when executing any life cycle costing analysis, regardless of agency, appropriation, or timing.

As discussed in Section 4.6.2 of the DoD Product Support BCA Guidebook, cost estimations compile and forecast the costs to perform the tasks associated with each Integrated Product Support (IPS) Element, for each alternative, during a specified time period of analysis (the life cycle). Cost considerations must be included in every decision relating to resource allocation. The appropriate cost-estimating method depends on the program being evaluated and the availability of data.

At a minimum, the DoD Product Support BCA Guidebook states that should work within the following guidelines (most of which are also addressed in DoD 5000.4-M and other cost analysis guides):

- Include all incremental, direct, and indirect costs to the taxpayer, which includes costs external to DoD and borne by society;
- Support the comparative analysis process by fully documenting the status quo (existing system) and providing its cost estimate;
- Include all relevant anticipated direct and indirect costs associated with each feasible alternative over the life of the program;
- Show all resources—including natural resources such as water and land—required to achieve the stated objective;
- Estimate all future costs from the start of the earliest alternative (other than the status quo) through implementation, operation, and disposal for a program or project;
- In the disposal phase, include the cost of disposal, and/or residual value for the old unit;
- Ensure that cost estimates are consistent with the assumptions, ground rules, and objectives of the product support strategy;
- Estimate all relevant future costs from inception through implementation, operation, and disposal for the program or project;
- Devote the appropriate time to the more significant cost driving elements, which discusses the concept of using a LCC profile to identify cost drivers and cost clusters. The cost of an alternative includes the cost of operating the status quo programs until the chosen alternative is fully implemented;

- Do not include sunk costs as part of the evaluation, analysis, or recommendation; and
- Disclose confidence levels per the Weapon System Acquisition Reform Act (WSARA) of 2009.

2.1.2 Standardized Cost Element Structures by Acquisition Phase

As DoD 5000.4-M indicates, LCC should be captured under the following four high-level categories:

- **Research and Development (R&D)**. This category consists of development costs incurred from the beginning of the materiel solutions analysis phase through the end of the engineering and manufacturing development phase and potentially into low rate initial production. Major elements of R&D costs include: development engineering; prototype manufacturing; system test and evaluation; and systems engineering and program management.
- **Investment**. This category includes production and deployment costs incurred from the beginning of low-rate initial production through completion of deployment. Include military construction costs in this category. Major elements of investment costs include: non-recurring production; recurring production; engineering changes; system test and evaluation; training devices and simulators; and program management.
- **Operations and Support (O&S)**. This category includes costs incurred from the initial system deployment through the end of system operations. It includes all costs of operating, maintaining, and supporting a fielded system. Specifically, this category consists of direct or indirect costs incurred by the government and contractors for personnel, equipment, supplies, software, and services associated with operating, modifying, maintaining, supplying, training, and supporting a system in the DoD inventory. Analysts can find additional, detailed guidance for estimating O&S costs in the latest edition of the DoD OSD Cost Assessment and Program Evaluation (CAPE) O&S Cost Estimating Guide. The guide calls for an O&S cost element structure divided into six (6) major categories, as follows: unit-level manpower; unit operations; maintenance; sustaining support; continuing system improvements; and indirect support.
- **Disposal**. This category consists of costs associated with the demilitarization and disposal of a military system at the end of its useful life. Demilitarization and disposal costs of a system can be significant. DoD 5000.4-M does not provide specific guidance on the estimation of these costs. Therefore, system-specific factors and other information should be used when developing these estimates. These costs should include any natural resource requirements and environmental-compliance-related costs. As an example, deactivation of some weapons platforms requires the use of land for long-term storage of the deactivated systems

Each military department has developed a cost element structure that varies slightly. The cost element structure for the department making the acquisition should be used and referenced in the Sustainability Analysis.

2.1.3 Sustainability-Related Cost Data

Traditionally, sustainability-related internal costs (direct, indirect, and contingent) are not systematically collected or are hidden in aggregated cost data. Table 1 provides DoD-specific examples for these types of costs, with examples drawn from existing guidance and expert judgment.

Table 1. Examples of Potentially Hidden and Contingent Sustainability-Related Costs

Potentially Hidden		Contingent
Non-Recurring	Support costs for the system	Increased price of system inputs
	Environmental-related R&D	Medical costs for active DoD personnel
	NEPA studies	Environmental clean-up (e.g., remediation, reclamation, restoration)
	Equipment Controls	Additional training
	Personal protective equipment (PPE)	Changes in regulation and additional compliance
	Industrial staging areas	Legal expenses
	Training	Damage payments
Recurring	Storage	Penalties and fines
	Conservation	Future audits
	Pollution prevention	R&D to mitigate hazard
	Permitting	Future land restrictions
	Compliance administration	
	Waste (solid and hazmat) management	
	Medical surveillance	
	Training	

To identify contingent costs, it is incumbent upon the analyst to use the systems perspective and life cycle approaches of the Sustainability Analysis. First, the inputs and outputs identified in the life cycle inventories stage may identify the use of hazardous substances or excessive use of other resources that could adversely impact the warfighter, other DoD personnel, or local communities. Second, through inspection of the entire system under study, the analyst may become aware of other concerns that can be translated into contingent costs.

Once these potential concerns are identified, the analyst must estimate both costs and probabilities. As discussed in the DoD Product Support BCA Guidebook (US DoD, 2011), an impact of occurrence and probability are required to assess the severity of a risk. The combination of the two gives an indication of overall risk (see Figure 4 in the Product Support BCA Guidebook). In the case of the Sustainability Analysis, the "impact" is expressed as a cost. Both the costs and the probability may be difficult to estimate; therefore, well-documented assumptions and innovative thinking must be applied to typical cost-estimating methods (engineering, parametric, analogy, expert opinion, and other, as described in the Product Support BCA Guidebook). Often, consultation with experts will provide the perspective necessary to estimate both cost and probability.

If it is found that these contingent cost estimates are important for comparing systems under study, then more effort can be expanded to refine the estimates later in the analysis.

Example: Estimation of contingent costs.

Scenario (1) Noise and occupational health

An analyst determines that the noise levels of a system under study will produce potentially hazardous working conditions, even for those employees wearing ear protection. After consultation with an expert, the analyst decides that there is a 10% probability that an individual employee will develop hearing impairment and require treatment. For those individuals who develop the hearing condition, the long-term care cost is estimated at $400,000 (present value) per employee. Finally, there will be approximately 50 employees working with the system over its lifetime. The contingent costs associated with the noise in the system would therefore be 50 x 0.1 x $400,000 = $2M.

Scenario (2) Water use in the region

Suppose that an analyst determines that the water demanded by a system may lead to water shortages in the area and thus lead to potential conflict within the local community. After a brief review of similar cases, the analyst estimates that there is a 30% probability that water demands in the region will continue to increase to the point that legal action is required. In that eventuality, the analyst assumes that the (present cost) of settling the dispute is $2.5 million. Therefore, the estimated contingent cost would be 0.3 x $2.5M = $750,000.

2.1.4 Additional Life Cycle Cost Guidance

In addition to DoD 5000.4-M and the DoD Product Support BCA Guide, other cost-estimating methods can be used such as the Government Accountability Office's (GAO's) Cost Estimating and Assessment Guide, the Army's Cost Benefit Analysis Guide, the Office of Management and Budget (OMB) Circular A-94, and other best-practice publications.

2.2 Life Cycle Assessment

LCA is a technique to quantify inputs (e.g., natural resources, materials, and chemicals) and outputs (e.g., environmental releases, waste) through each life cycle stage of a system, and estimate the impact of these flows on the environment and humans. In the Sustainability Analysis context, these impacts are representative of potential future liabilities to DoD. The results of an LCA are relative to a functional unit, which quantifies the purpose and required performance of the system. Since LCA provides relative results, rather than absolute results, the results of two LCAs can be compared only if the functional units are identical.

2.2.1 Life Cycle Assessment Standards

The International Organization for Standardization (ISO), a worldwide federation of national standards bodies, has developed a set of LCA standards. The LCA component of the Sustainability Analysis must be consistent with ISO 14040, which describes the principles and framework for LCA, and ISO 14044, which specifies requirements and provides guidelines for performing an LCA. The stages of an LCA as described in the ISO LCA standards are illustrated in Figure 7 and described below.

- **Goal and scope definition**. Goals are defined to specify the intended application, reasons for conducting the study, intended audience, and how the results will be used. Next, the scope, including the breadth, depth, and details of the study, is described to ensure achievement of stated goals.
- **Inventory analysis**. Data are collected and calculations are performed to quantify inputs and outputs relevant to the study goal and scope. Inputs include energy, chemicals and materials, natural resources, and other physical inputs required at each life cycle stage of the system under study. Outputs include products, co-products, waste, emissions to air, discharges to water and soil, and other environmental aspects that are generated at each life cycle stage of the system

under study. The life cycle inventory (LCI) aggregates and reduces all inputs and outputs into elementary flows, i.e., basic materials and energy drawn from the environment (e.g., ore, coal, water) or released to the environment (e.g., carbon dioxide emissions to air, trichloroethylene releases to groundwater).

- **Impact assessment**. The significance of potential environmental impacts is evaluated using the LCI results and life cycle impact assessment (LCIA) models. First, the elementary flows identified in the LCI are assigned to environmental impact categories. An impact category represents an environmental issue of concern. For example, "fossil energy use (MJ)" is an impact category for assessing the potential impacts from depleting fossil fuel resources. "Climate change (Kg CO2 equivalent)" is an impact category for assessing the potential impacts from releases of greenhouse gases into the atmosphere and contributing to global warming. Next, the impact from the elementary flows are calculated for each impact category. LCA researchers and practitioners have developed characterization models to translate elementary flows to potential impact for each impact category. See Section 3.4 for further discussion of these models.

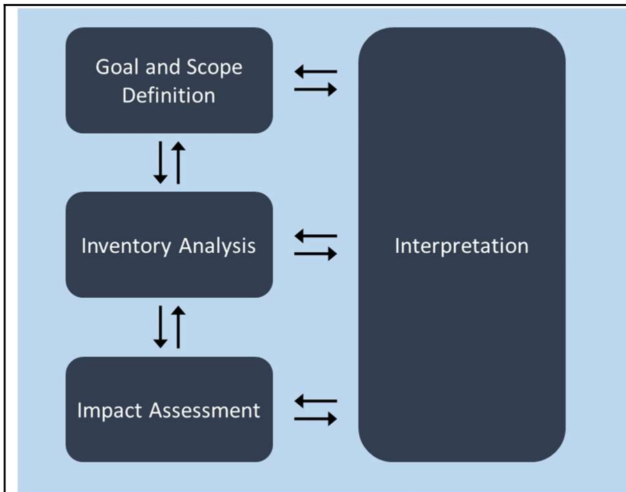

Figure 7. Stages of a Life Cycle Assessment per ISO 14040

- **Interpretation**. The results of the inventory analysis and the impact assessment are considered together to draw conclusions and provide recommendations consistent with the goal and scope of the study.

LCA is an iterative process. Each stage of an LCA uses results from the other stages. For example, the impact assessment directly uses the results of the inventory analysis to quantify potential environmental impact. In addition, findings from one stage may necessitate changes from other stages. For example, data limitations or additional information about life cycle activities identified in the inventory analysis may require revisions to the goal and scope of the study. The Sustainability Analysis procedures described in the next section (Section 3) are based on the stages detailed in the ISO 14040 standards, with one exception—the described procedures integrate LCC and LCA to provide a more comprehensive Sustainability Analysis.

2.2.2 Established LCA Methods and Models

There are a number of methods and models for capturing input and output data, translating inputs and outputs into potential impact, and presenting and interpreting the inventory and impact assessment results. As detailed in the next section (Section 3), a set of methods and models have been selected and integrated to streamline and ensure a consistent process for conducting Sustainability Analyses for the DoD.

2.3 Underlying Assumptions for the Sustainability Analysis

As with LCC and TOC estimates, a Sustainability Analysis should generally reflect peacetime conditions. DoD considers the incremental costs due to a contingency or emergency operation[6] to be part of the cost of the operation, not part of acquisition costs. Therefore, the Sustainability Analysis should represent a baseline based on peacetime or business as usual conditions.

2.4 Framework

Figure 8 provides an overview of the DoD Sustainability Analysis framework, which utilizes LCC for evaluating internal costs and LCA for evaluating potential impact and external cost.

1. **LCI** data is collected; these data capture the costs and physical flows (both inputs and outputs) associated with activities in the system life cycle
2. **Internal Costs** (i.e., direct and indirect costs) are estimated.
3. **Midpoint and Endpoint Impacts** are calculated from the elementary flows in the LCI through use of characterization factors from a life cycle impact assessment model, such as the Defense Input-Output (DIO) database.
4. **External cost** (or externalities) are estimated through use of external cost factors associated with the endpoint impacts. These costs represent the potential environmental liabilities to DoD, though the costs are borne by non-DoD government agencies or society at large.
5. **Contingent costs** result from possible future events that result in additional internal costs to DoD.
6. **Iterate** as needed, including reevaluation of data and assumptions in previous steps.

Internal, contingent, and external costs should not be aggregated; rather, they should be reported and considered in parallel to better understand the costs and risks to both DoD and society. Further reporting requirements are found in Section 4.0

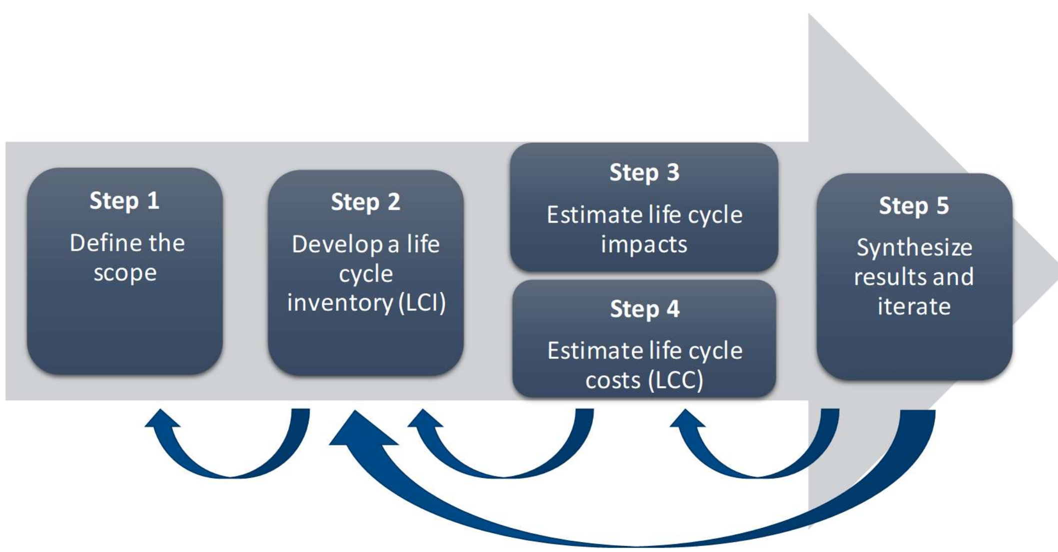

Figure 8. Overview of Sustainability Analysis Framework

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[6] Includes combat operations as well as military operations other than war (MOOTW)

3 Procedure for Conducting Sustainability Analyses

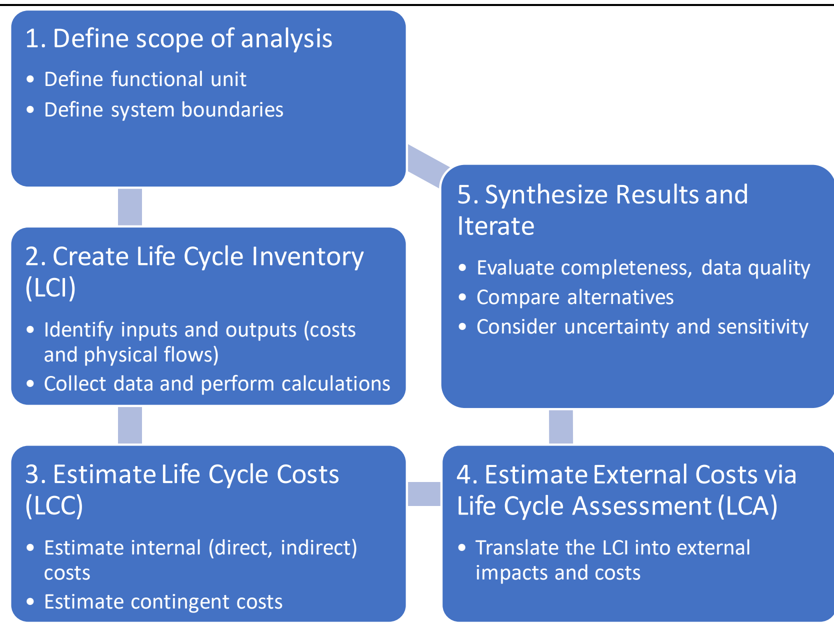

Figure 9. Five Iterative Steps of a Sustainability Analysis

The five steps of a Sustainability Analysis, illustrated in Figure 9, are used to conduct a Sustainability Analysis. To complete these steps, the scope of the analysis is first defined (Step 1). Then, cost data is collected for upstream (i.e., supply chain) activities; input, output, and cost data are collected for downstream activities, which may include OEM, DoD, and sustainment contractor activities; and these data are aggregated to generate LCI data. Next, established LCC guidelines and best practices are used to develop an LCC estimate (Step 3). Then, LCA models are used to translate the inputs and outputs of the LCI into potential environmental impact, expressed as external costs. Finally, the results are evaluated and updated as necessary to develop a robust understanding of life cycle impacts and costs, with potential iteration.

The Defense-Input Output Database and Other Tools for Sustainability Analysis

As described in Section 3.2, the Sustainability Analysis requires the collection of data that will have been gathered for other acquisition analyses. As data are collected, the analysis requires consistent record-keeping of all the inputs and outputs associated with the LCI. The LCC portion of the analysis incorporates financial mechanisms of discounting costs for a consistent comparison.

The External Costing (LCA) step of the analysis does require two auxiliary inputs:

1. Data of inputs and outputs for upstream activities required to purchase essential goods or services (e.g., if the system under study uses paint, the user may not know the raw materials, electricity, water, etc. required to produce that paint).
2. Models to translate inputs and outputs into potential environmental and human health impacts of releases (e.g., electricity production often implies combustion; the particulate matter released by that combustion may affect the local population).

DoD has developed a database, called the Defense Input Output (DIO) database to provide these two auxiliary inputs, supporting the DoD acquisition community in conducting the Sustainability Analysis. The DIO dataset facilitates completion of Steps 2-4 described in Figure 9. The DIO dataset:

- Augments collected data and enables a more complete LCI.
- Relies on publicly available data to estimate upstream (i.e., supply chain) inputs and outputs from purchased goods and services and some DoD activities.[7]
- Uses publicly available and peer-reviewed methods for translating life cycle inputs and outputs into life cycle impacts and external costs.
- Achieves a balance between accuracy and level of effort.
- Enables a consistent approach for conducting Sustainability Analyses across the DoD.
- Supports the completion of Sustainability Analyses by non-LCA experts.

In addition, there are other tools to assist users with the Sustainability Analysis process. The DIO is part of the first two, and may be used with the third:

- **Scoring factors**. The scoring factors support manual completion of a Sustainability Analysis. The impact for a unit of each procured good or service, activity, and elementary flow included in the DIO dataset was calculated. The results, called scoring factors, are provided in a Microsoft Excel spreadsheet[8]. When conducting a Sustainability Analysis, the analyst can complete Steps 1 and 2 to calculate all inputs and outputs. The total quantity of the inputs and outputs are then multiplied by the associated scoring factor to calculate impacts (midpoint and endpoint) and external cost (Steps 3 and 4). The analyst must calculate internal costs separately using established LCC guidelines and best practices.
- **Web-based tool**. A web-based tool has been developed for conducting a DoD Sustainability Analysis. It uses a user-friendly interface to guide the user through the 5-step process using DoD acquisition language. It completes the LCA and LCC estimate simultaneously and uses the DIO database. Internal costs are calculated in accordance with established LCC guidelines and best practices.
- **LCA Software**. The data behind the DIO method is available for organizations that use commercial off-the-shelf (COTS), open source, or proprietary LCA software. This allows LCA experts to integrate the DIO method with their LCA data to conduct more detailed and accurate Sustainability Analyses consistent with the DoD Sustainability Analysis framework.

The five steps for performing the Sustainability Analysis in Figure 9 are described below. More information about accessing and using each of these resources is available on the Defense Environmental Network and Information Exchange (DENIX) ESOH in Acquisition website.[9]

3.1 Step 1 - Define the Scope of the Analysis

The first step of the Sustainability Analysis is to define the goals and scope of the analysis, including the following:

- Reasons for conducting the Sustainability Analysis
- Description of the systems to be analyzed

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[7] The first version of the DIO method included procured goods and services, energy use, and transportation. Future release may include additional DoD activities.
[8] DoD Sustainability Assessment Guidance - Appendix I Scoring Factors. Retrieved from: https://www.denix.osd.mil/esohacq/home/
[9] http://www.denix.osd.mil/esohacq/

- Functions of the system that will be used to define system performance
- Functional unit for quantifying required performance
- Reference flow for establishing equivalence between alternatives
- System boundaries that identify aspects of the system life cycle included in the analysis
- Impacts and costs that will be analyzed

A Sustainability Analysis is suited for comparing costs and potential environmental liabilities of systems that meet a stated mission or performance requirement; the analysis does not replace the performance requirements but rather enhances the acquisition community's efforts to make fiscally sound, long-term decisions.

3.1.1 Parameters

The assumptions and parameters used to define the scope of the analysis and specify how economic comparisons will be made should be clearly defined. These include:

- **Reference year**. A reference year should be selected to enable comparison of internal and external costs for all alternatives in constant dollars. Generally, the reference year is set as the current year, the beginning of the study period, or the baseline year for the program.
- **Study period.** The number of years the Sustainability Analysis is based on must be established. The study period should be based on the "economic life" of the project, i.e., the period of time for which the costs and benefits will be evaluated. This will not necessarily be the same as the anticipated service life of the alternatives.
- **Inflation Rates.** OMB Circular A-94 (US OMB, 2017) defines inflation as "the proportionate rate of change in the general price level, as opposed to the proportionate increase in a specific price." Inflation represents a decrease in the value of money. Costs specified for years occurring before the reference must be inflated to the reference year. Industry-specific (escalation rates) and economy-wide inflation factors can be derived using the Producer Price Index (PPI), produced by the Bureau of Labor Statistics (BLS).[10]
- **Escalation Rates.** The term "escalation" refers to price changes of particular goods and services,[11] which is distinct from inflation (CAPE, 2017). Cost estimates that forecast funding requirements for weapons systems often incorporate escalation rates. Analysts are responsible for determining which escalation assumptions are appropriate and where they are applicable. In addition to industry-specific factors produced by BLS, the DoD publishes several escalation indexes. The DoD Escalation Handbook (CAPE, 2017) provides additional guidance on level of detail needed and how to choose escalation indexes.
- **Real Discount Rate.** Throughout a Sustainability Analysis costs should be specified in constant-dollars, generally normalized (i.e., inflated or discounted) to the reference year. To account for the time value of money, discounted (net present value) financial cost estimates should be derived using the real discount rate Appendix C of OMB Circular A-94. This includes both internal and contingent cost estimates.

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[10] http://www.bls.gov/ppi/

[11] The DoD Handbook for *Inflation and Escalation Best Practice for Cost Analysis* notes that, "equivalent terms to escalation include price change, market price change, specific price change/growth, and price escalation." (CAPE, 2017)

- **Social Discount Rate.** To account for revealed time preferences and opportunity costs (i.e., placing more value on benefits or costs incurred now than those incurred in the future), a social discount rate should be used to derive a discounted (present value) external cost estimate. OMB Circular A-4 suggests a discount rate between 3% and 7% except in the case of important intergenerational benefits or costs, where discount rates between 1% and 3% may be more appropriate. A 3% discount rate is a reasonable starting point for calculating present value external cost estimates.

3.1.2 Functional Unit

A Sustainability Analysis should be conducted relative to a functional unit, which quantifies the required performance of the system (ISO, 2006). The functional unit should be defined by the minimal performance requirements needed to properly meet the stated capability, as outlined in the ICD, the CDD, or a specific component performance requirement or specification. The functional unit should be the same for all evaluated alternatives. A few illustrative examples include:

- **Performance requirements**, e.g., comparing aircraft wing designs based on one or more common performance parameters, such as wingspan limits, payload, or other requirements as specified in the ICD or CDD.
- **Sustainment requirements**, e.g., comparing the incumbent and alternative coatings for maintaining weapon system landing gear based on one or more common performance parameters, such as required coating adhesion, corrosion protection, tensile strength, and hardness.

3.1.3 System-Level Reference Flow

Once the functional unit is defined, a reference flow must be defined for each alternative. The reference activity, and its output (flow) specifies the amount of each alterative required to fulfil the function defined by the functional unit. Reference flows ensure comparability of LCA results for each alternative analyzed. A few illustrative examples include:

- **Number required to perform a mission**, e.g., comparing two small helicopters to one large helicopter, which can satisfy the same mission.
- **Amount needed for sustainment**, e.g., comparing two layers of coating X to one layer of coating Y, which can satisfy the same corrosion protection over a specified area and period of time.
- **Number required to fulfil required service life**, e.g., comparing two alternatives that must meet a capability over a 50-year period. The first alternative has a life span of 25 years, and the second alternative has a life span of 50 years. Two units of the first alternative would be required, whereas one of the second alternative would be required.

3.1.4 Activity-Level Flows

The system-level reference flow determines activity-level flows. Activities produce outputs (flows) required to create or achieve the system reference flow or other activities. Supporting activities could include the following:

- **Purchase and maintenance**, e.g., if a helicopter(s) with a given cargo capacity is the system-level reference flow, then the supporting activities might be the purchase of the helicopter(s), the maintenance of the helicopter, and the fuel for the helicopter. Each of the supporting activities, in turn, has supporting activities: a certain amount of metal, paint, electronics is needed to manufacture the helicopter. Stripping and painting could be required for maintenance. Refining and transport could be required for the fuel.

- **Sustainment activities**, e.g., if a corrosion protection coating sustainment is the system-level reference flow, then a stripping step and plating bath could be supporting activities. In turn, those supporting activities would require their own activities, such as materials and labor for stripping, or reagents and electricity for plating.

Fully modeling the reference flow requires fully modeling the entire supply chain for all of the inputs to the reference activity. While the first-tier supporting activities may be well-known to the analyst (as in the examples above), second-tier (those activities required for the first-tier) supporting activities are often less well-known to the analyst, and so on. It is impractical to model the entire supply chain. The DIO database provides a convenient means to tap into an extensive supply chain model. For example, an analyst may know that electricity is consumed by a first-tier activity, but the analyst cannot model all of the resources, distribution systems, etc. required to produce and deliver electricity from the grid; the DIO has this information (in an aggregated form), providing the full upstream supply chain of that electricity.

Flows are typically expressed in physical units (e.g., mass, volume, area), but can also be expressed in monetary units (e.g., dollars) when representing a procured item or service for which the physical unit is unknown.

3.1.5 System Boundary

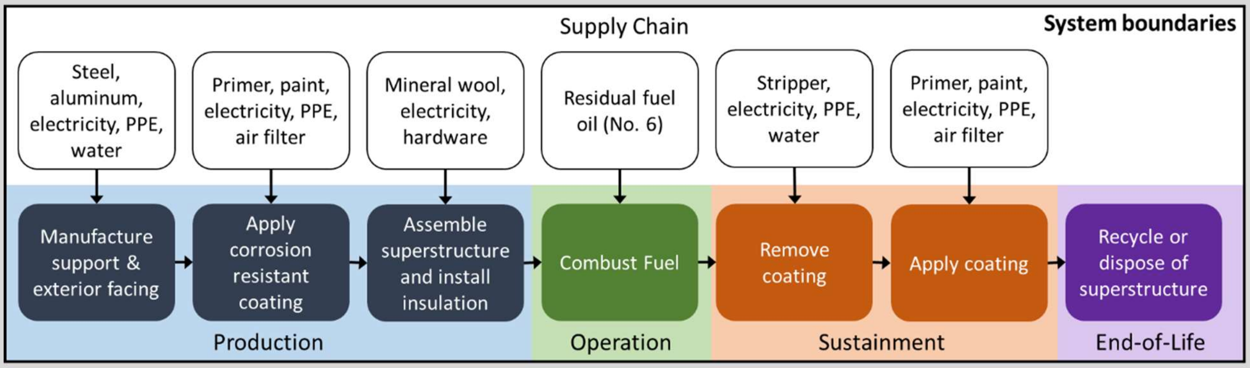
The system boundary defines which life cycle stages and associated activities will be included in the Sustainability Analysis. All stages of the system's life cycle (i.e., production, operation, sustainment, and disposal) should be considered when defining the system boundaries. Activities outside of a system's life cycle, but impacted by the alternatives being considered, should also be included in the system boundaries. For example, alternative component designs for a weapon system that have a difference in weight may cause a weapon system to consume more fuel. This difference in the weapon system's fuel consumption should be included in the system boundaries. In contrast, life cycle stages or specific activities that are likely immaterial or identical between the alternatives can be excluded. Such exclusions can reduce the level of effort to complete a Sustainability Analysis, while still providing an equivalent comparison between alternative and informing specific acquisition decisions. However, these exclusions result in a truncated Sustainability Analysis. Therefore, all exclusions must be explicitly identified. For each alternative, the system boundaries should be defined consistently with the study goals, scope, and functional unit as well as the specific alternative's reference flow. Process flow diagrams are generally used to portray the system boundaries for each alternative.

Notional Noncombat Ship Superstructure Sustainability Analysis – Scope and System Boundaries

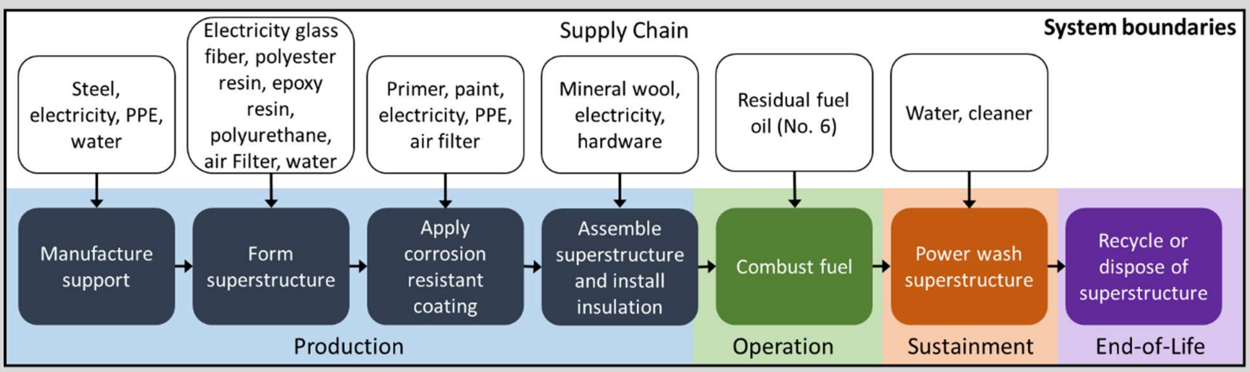
The figures below illustrate hypothetical system boundaries for comparing two material alternatives for a noncombat ship's superstructure. In this example, the Sustainability Analysis is comparing the two alternatives for the superstructure, and the first step is to identify system boundaries for each alternative.

The superstructure includes the parts of a ship that project above the ship's main deck and provide shelter to passengers. Two material alternatives are considered – steel and a composite. The steel superstructure consists of a recycled steel support with recycled aluminum outer facing. A corrosion resistant coating system is applied to the steel superstructure. Mineral wool insulation is applied to the superstructure to provide fire, thermal, and acoustic insulation. During sustainment, this coating must be removed and the steel superstructure recoated. The composite superstructure is a sandwich composite construction that consists of two (2) glass fiber-reinforced polymer laminate on each side of a core of lightweight polyvinyl chloride foam with steel support. A corrosion resistant coating is applied to the composite superstructure during manufacturing. During sustainment, the composite superstructure must be power washed. Since the mass of the superstructure will differ between the two (2) alternatives, it is necessary to consider fuel consumption. During operation, Residual Fuel Oil (No. 6) is heated and burned to power the ship.

Steel Alternative



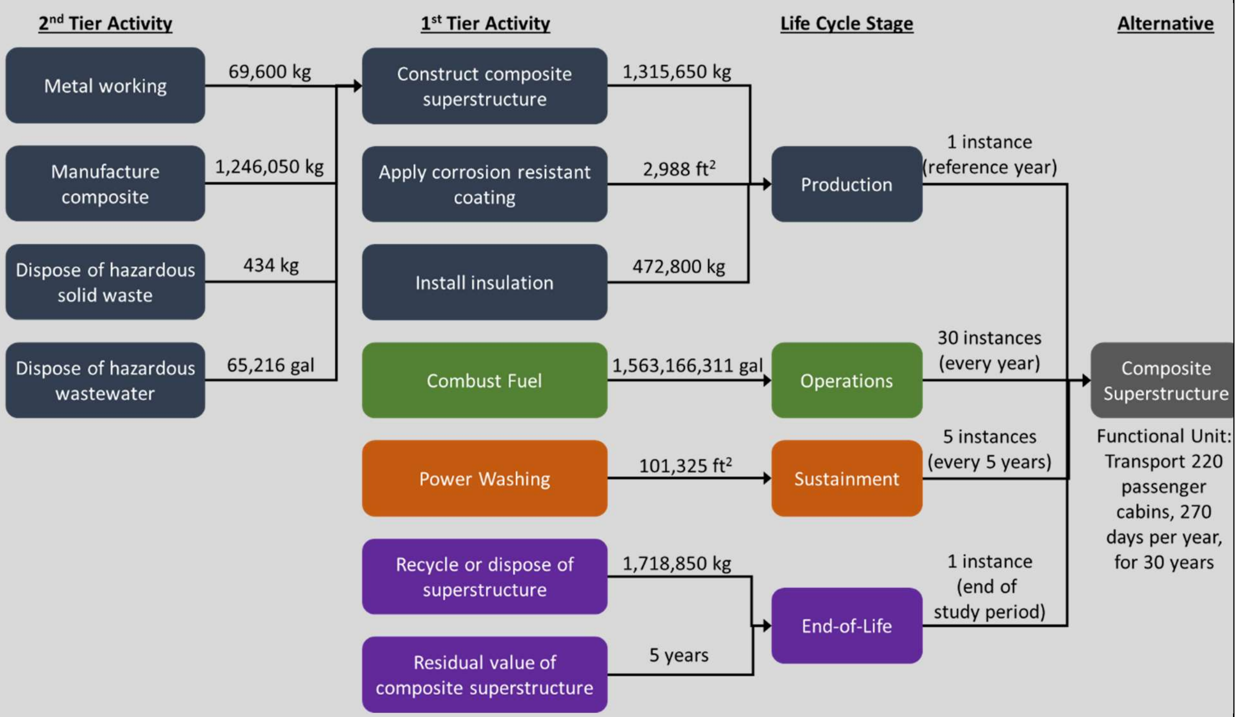
Composite Alternative



Illustrative System Boundaries for Notional Superstructure Comparison

Notional Noncombat Ship Superstructure Sustainability Analysis – Process Flow Diagram

The illustrations in the previous example provide a high level overview of the system boundaries, facilitating a general understanding of the systems and enabling comparison of the two alternatives side-by-side. To facilitate a more complete understanding and robust modeling of each alternative, it is necessary to develop detailed process flow diagrams. A process flow diagram uses a tiered approach to show the sequence by which activities occur across the life cycle as well as the interdependencies between activities. The illustration below provides a partial diagram for the composite superstructure alternative. When creating a process flow diagram, the connecting lines between activities and life cycle stages represent the reference flow for each activity (i.e., the amount required to satisfy the functional unit). Note that each activity can represent costs (internal, contingent, or external) to the system.



Illustrative Partial Process Flow Diagram for the Composite Ship Superstructure

3.1.6 Specify Allocation Procedures

Inputs and outputs are quantified and assigned to a system on a functional unit basis. Several scenarios arise where inputs and outputs are distributed across multiple systems or multiple life cycles for the same systems. To ensure system equivalency between the alternatives under consideration, it is necessary to partition inputs and outputs on a functional unit basis. There following situations generally require use of allocation.

- **Multi-functional systems.** The system may provide more than one function. Likewise, activities occurring within the system's life cycle may provide more than one product – the product used in the system's life cycle and one or more co-products used for other systems. If possible, allocation should be avoided by subdividing activities, through system expansion, or through substitution. When subdividing the activities, the multi-product activity is divided into sub-activities such that the inputs, outputs, and costs are assigned directly to the product of interest and its co-products. When using system expansion, the system boundaries for all alternatives are changed to include the extra functions or co-products. Substitution, which is a form of system expansion, can be used when the co-product is normally produces in another manner. In this approach, it is assumed that production of the co-product offsets the need to produce it in the normal manner. The system boundary is expanded to include the co-product, but subtracts the inputs, outputs, and costs from the "avoided" activities that would have been required to produce the co-product in the normal manner. When it cannot be avoided, allocation what can be used to partition inputs, outputs, and costs to the product and co-products in proportion to a defined criterion, such as product mass, energy content, or monetary value. Regardless of which method is used (i.e., subdividing activities, system expansion, substitution, or allocation), the goal is to provide system equivalence by including only the inputs, outputs, and costs associated with functional unit for each alternative.

- **Recycled or reused products.** Reused or recycled system components and waste streams (hereafter referred to as material) result in hidden value. The activity generating the reusable or recyclable material should be given a credit to offset the inputs, outputs, and costs associated with using the material. Reusing and recycling material alleviates the need to harvest virgin material or purchase material altogether, thus displacing the impacts and costs associated with raw material extraction and processing. Modeling the benefits of reuse and recycling is susceptible to double-counting, e.g., when a credit is given to both the original system containing recyclable material as well as the second system using the recycled material. For a Sustainability Analysis, a combination of substitution and allocation based on monetary value should be used to partition the benefits between the two systems. When materials used in a system will be recycled, the system should receive a credit equal to the residual value of the waste materials. Residual value is quantified as the value of the material in a secondary market. The credit is calculated by multiplying the inputs, outputs, and costs by the ratio of secondary market value of the material to the original purchase price of the material.
- **System life extends beyond the defined study period.** Alternatives within a study often have different life spans. Ideally, the functional unit will represent the lowest common denominator for the life spans across all alternatives. However, it is not always possible to find a lowest common denominator for all alternatives. Some systems' life spans will exceed the study period. For a Sustainability Analysis, a combination of substitution and allocation based on monetary value should be used to credit an alternative with a life span that exceeds the study period. The additional useful life displaces the need to purchase a new system, and therefore offsets the impacts and costs associated with producing a new system. The residual value of the system will be used to calculate the allocation partitioning factor. In this context, the term residual value refers to the terminal value of the system, i.e., the remaining value of the asset after depreciation at the end of the study period, not the salvage value of the asset at the end of its useful life. When the appropriate depreciation method is unknown, use the Straight Line Depreciation method to approximate the residual value. Impacts are allocated and displaced according to the allocation partitioning factor, which is calculated by dividing the residual value by the system's initial value. For costing purposes, the resulting impacts and associated costs should be recorded in the final year of the analysis and discounted back to the reference year.

3.2 Step 2 – Develop a Life Cycle Inventory

LCI data are collected and used to calculate the inputs and outputs associated with every activity included in the system boundaries.

- From an LCC perspective, inventory includes the financial costs incurred by DoD for all activities included in the system boundaries. Costs should be categorized as direct, indirect, or contingent. Costs of purchasing inputs (e.g., fuel, reagents) and disposing of outputs (e.g., hazardous waste, non-hazardous waste) are both costs; any income generated (e.g., from selling a useful by-product) could be counted as a negative cost.

- From an LCA perspective, inputs include energy, chemicals and materials, land, water, and other resources used. Outputs include environmental discharges, waste, noise, and other releases to the environment.

For the purpose of the Sustainability Analysis, the LCI includes all inputs, outputs, and costs. They shall be quantified in relation to the functional unit defined in the scope (Step 1). Costs are used to generate a LCC estimate. To complete the LCA portion of the analysis, all inputs and outputs are reduced to their elementary flows and aggregated together (UNEP/SETAC Life Cycle Initiative, 2011). Elementary inputs come directly from the environment (e.g., crude oil, minerals, land, and water). Elementary outputs go directly to the environment (e.g., air emissions, water releases, noise).

Sustainability Analysis consists of an integrated-hybrid approach that combines two existing methodologies to calculate elementary flows:

- **Process-based LCA** is a bottom-up approach in which LCI data are collected for every activity within the system boundaries. Data are collected and processed to estimate all of the inputs (i.e., include energy, chemicals and materials, land, water, and other resources) and outputs (i.e., environmental discharges, waste, noise, and other releases to the environment). Data sources include process engineers, environmental health and safety professionals, operators, product manufacturers, industry experts, available literature, and existing LCI datasets. In general, process-based LCA should be used to analyze DoD, prime OEM, and sustainment contractor activities, as these are the activities that are central to the activity under study and should, in theory, have data available. Process-based LCA results in detailed and actionable results that can be used, for example, to inform design decisions, compare specific alternatives, or identify specific process changes for reducing significant impacts. However, it is generally not practical to collect LCI data for the entire supply chain. Limiting the scope of the process-based results in an incomplete model of the system and leads to truncation error, i.e., omission of resource inputs and environmental outputs from the system's supply chain.
- **Environmentally Extended Input-Output (EEIO) analysis** relate economic activity from economic input–output (I-O) models, which quantify the interdependencies and associated financial transactions between industrial sectors in an economy, to resource consumption and environmental releases for each sector to estimate supply chain impacts from purchased goods and services. Several EEIO models have been built for the U.S. and other economies. The user enters the cost of a purchased good or service, and the model estimates the amount of resources consumed (i.e., inputs) and environmental releases (i.e., outputs) across the economy. This approach follows the flow of money through the economy, from direct transactions with first tier suppliers through the associated indirect transactions from all other sectors throughout the supply chain. In general, EEIO analysis can be used as a screening-level analysis to assess the relative importance of supply chain impacts and identify supply chain activities that may have large impacts (sometimes called a hotspot analysis). To inform specific acquisition decisions, it may be necessary to assess supply chain activities with large potential impacts more thoroughly using process-based LCA. In general, EEIO analysis should be used to analyze the impacts associated with purchased goods and services used by the DoD, Prime OEMs, and sustainment contractors. Since EEIO analysis utilizes established EEIO models, it requires minimal original data collection (i.e., the cost of the purchased good or service). It provides a consistent framework for generating rapid estimates of supply chain resource requirements and environmental releases. However, there are several important limitations associated with relying solely on EEIO analysis. It reflects average conditions within a sector, does not distinguish between products within a

sector, assumes linear proportionality between economic activity and environmental burdens, does not distinguish between domestically produced goods and imports, and is very sensitive to price fluctuations.

The **hybrid life cycle assessment** methodology used to conduct a DoD Sustainability Analysis connects process-based LCA and EEIO analysis. The analyst is given the ability to model activities explicitly when data are available, and to model activities using the EEIO approach in other cases. The hybrid approach reduces truncation error by including extended supply chain impacts. Hybrid LCA is used to achieve a balance between accuracy and level of effort.

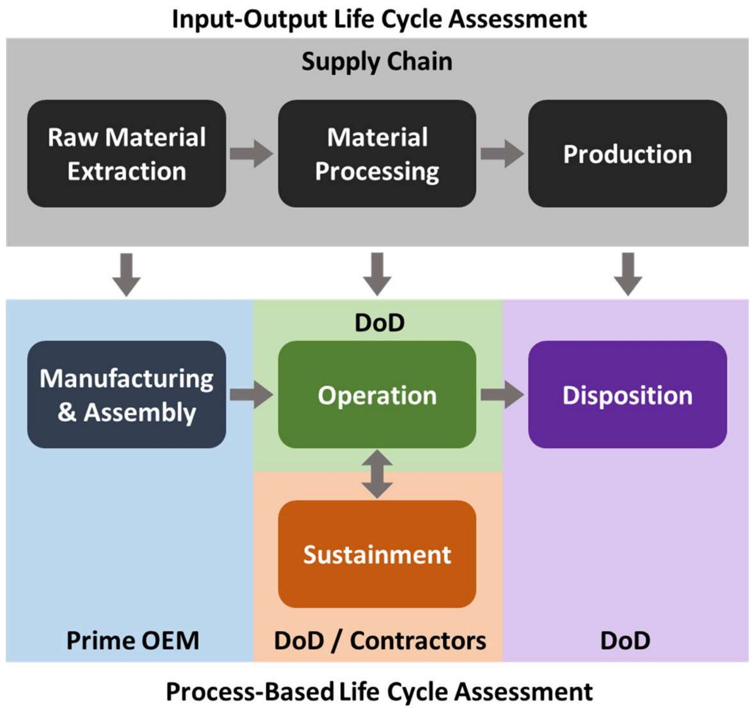


Figure 10. Sustainability Analysis of Defense Systems Using Hybrid Life Cycle Assessment

3.2.1 Approach for Developing a Life Cycle Inventory

LCI data are collected at the activity level and aggregated to create an LCI, which includes an inventory of elementary flows and an initial LCC estimate. The aggregated results should be normalized to the reference flow of the functional unit, as defined by the scope of the Sustainability Analysis. The type of data required varies based the scope of the Sustainability Analysis, LCA approach used (process-based LCA, EEIO analysis, or hybrid LCA), and availability of appropriate LCI data. The following steps are based on using the DIO dataset.

- **Specify the reference flow for each activity** (i.e., the amount required to fulfil the functional unit). The inputs and outputs for each activity will be quantified relative to this reference flow.
- **Identify inputs** required for each activity included in the system boundary. Inputs include procured goods (e.g., chemicals and materials, equipment, permits, personal protective equipment), procured services (e.g., waste management, construction), and direct resource use (e.g., energy, water, land) required throughout the system's life cycle. When identifying system

inputs, support systems or risk mitigation associated with those activities should be considered. For example, an alternative that requires the use of hazardous materials may require supporting systems and services (e.g., facility controls, PPE, waste management services) to mitigate health- and environmental-related risks.

- **Quantify inputs**. Each input should be recorded in the same physical units (e.g., megajoules, kilograms, flight-hours) or monetary units (i.e., U.S. Dollars) specified in the DIO dataset. For inputs specified in physical units in the DIO dataset, monetary units should also be recorded to complete the internal cost estimate. The DIO dataset classifies purchased goods and services by industry sector using the North American Industry Classification System (NAICS) code. Therefore the NAICS code for these inputs must be specified. The scoring factors and web-based tool provide guidance for assigning inputs to a NAICS sector. Additional guidance can be obtained from the U.S. Census Bureau.[12] The cost for each input should be recorded in constant dollars, and the year in which it occurs should be specified.
- **Normalize costs** to both the reference year of the DIO tool being used (i.e., the scoring factors, the web-based tool, or the DIO dataset) and the reference year of the Sustainability Analysis using the appropriate discount factors and inflation factors.
- **Convert purchaser prices to producer prices** if necessary. EEIO models, like that used in the DIO dataset, can be based on producer price (i.e., the cost to make the good or provide the service) or the purchaser price (i.e., the cost of the good or service to the consumer). The difference between the two is that purchaser price includes transportation, wholesale, and retail margins. The DIO model is based on producer price. If the cost specified for a purchased good or service represents producer price, a conversion is not necessary. If the cost represents purchaser price, it must be converted to producer price. This can be done by subtracting the transportation, wholesale, and retail margins from the purchaser price or using industry specific producer/purchaser price ratios.[13]
- **Identify outputs** resulting from the activities included in the system boundary. Outputs include products, air emissions, water releases, land releases, solid waste, hazardous waste, wastewater, and noise.
- **Quantify outputs.** All outputs should be quantified relative the amount of activity required to fulfil the functional unit. In general, physical units (e.g., kilograms, gallons) are used to quantify outputs. However, if an output generates procurement actions (e.g., waste treatment) or other internal costs, cost data should be collected as described above for the inputs. Releases to the environment should be quantified based on the released prior to any controls or treatment, the receiving environmental compartment should be identified (e.g., releases to air, soil, and water), and the population characteristics (urban, rural, indoor, or unspecified) at the release site should be specified. In general, managed waste is modeled as a procured service. Therefore, it is not necessary to specify specific chemicals and materials contained in the waste. If one or more co-products exist for an activity, including recycled/reused content, appropriate co-product accounting methods should be used to properly partition outputs to the system. All data collection methods, data sources, calculations, and allocation procedures should be clearly documented.

[12] http://www.census.gov/eos/www/naics/
[13] A producer/purchaser price transformation matrix will be made available on DENIX.

- **Allocate inputs and outputs** as necessary. If one or more co-products exist for an activity or for the system, appropriate co-product accounting methods should be used to properly partition inputs and outputs to the activity or system.

As an interim step in estimating impacts and external costs, the DIO tools convert all inputs and outputs into elementary flows. Therefore, it is not necessary to perform the step of translating input and output data into LCI data (i.e., elementary flows).

3.2.2 Data Collection

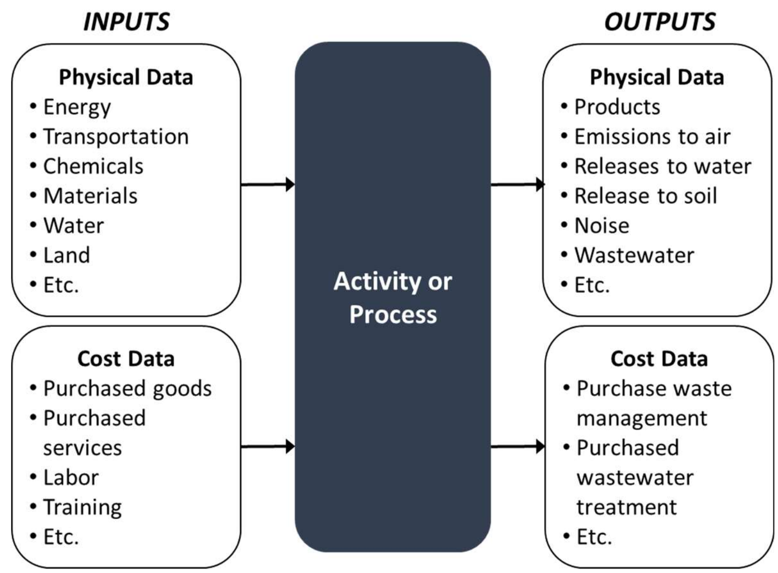
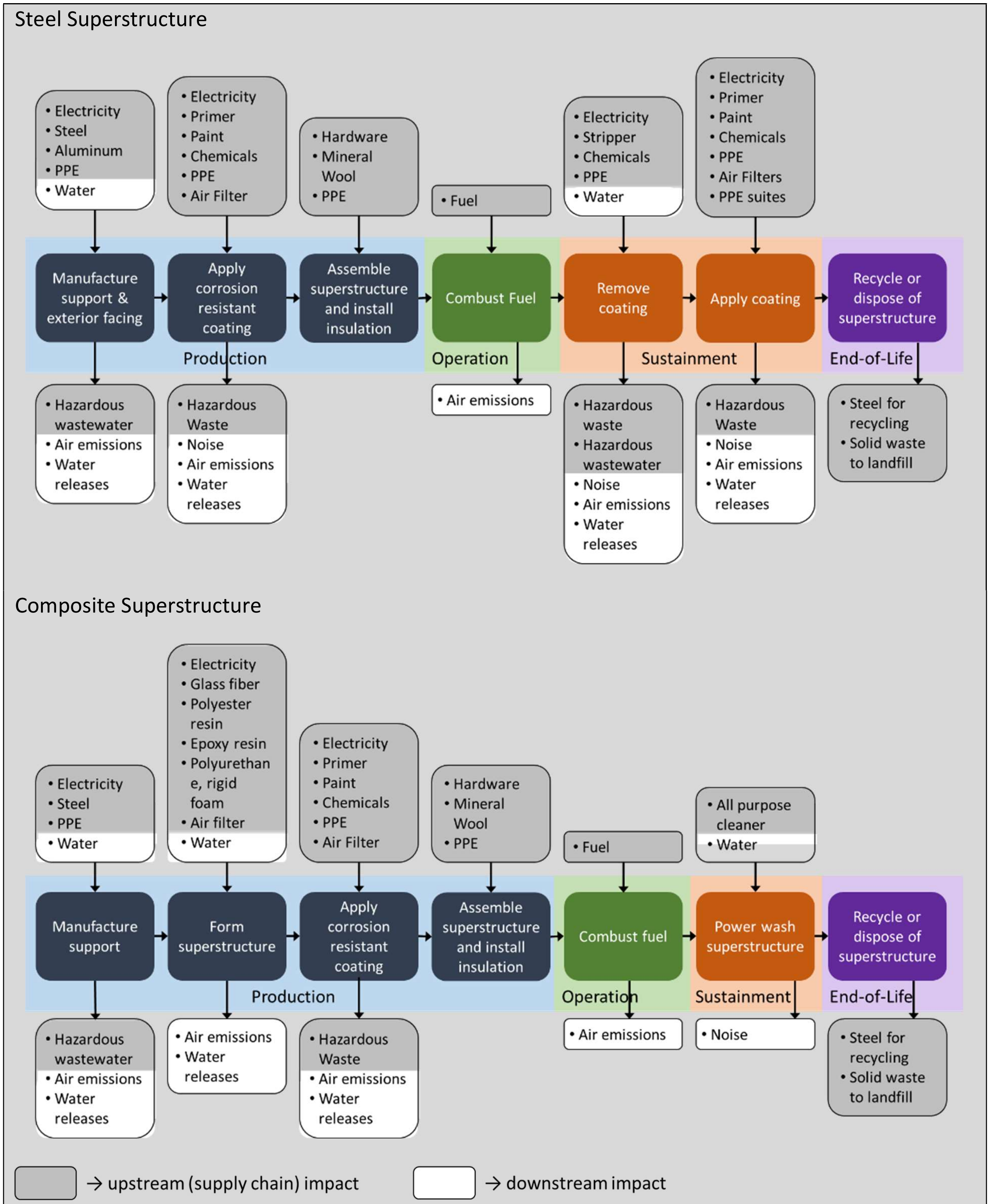


Figure 11. General Data Requirements for an Activity Included in a Sustainability Analysis (Based on using Hybrid LCA and LCC)

A Sustainability Analyses requires cost and physical data for every activity included in the system boundary, as illustrated in Figure 11 and detailed below. Data sources may include purchase records from similar existing systems and legacy systems, sustainment data for operation and maintenance of similar existing systems and legacy systems, an estimated bill of materials informed by initial designs or technology development activities, information from initial technology development testing, engineering or parametric estimates, existing LCI datasets, published literature, estimates from technical experts, and on-site measurements. The basis for the data should be clearly recorded, e.g., system-specific information, proxy systems (e.g., a similar existing or legacy system), calculated estimates, or expert judgement. All underlying assumption, any adjustments made to collected data, and any data limitations should be clearly documented.

Notional Noncombat Ship Superstructure Sustainability Analysis – Inputs and Outputs The inputs and outputs highlighted in gray represent procured goods and services. The associated elementary flows would be estimated using the DIO dataset. The inputs and outputs highlighted in white represent elementary flows directly attributed to an OEM, DoD, or a DoD sustainment contractor.



Illustrative Inputs and Outputs for Hypothetical Superstructure Comparison

3.3 Step 4 – Estimate Life Cycle Costs

LCI data also includes cost data for all activities within the system boundaries. The cost element structure for the LCC estimate should be defined in accordance with existing LCC guidance, including DoD Manual (DoDM) 5000.4-M, the Defense Acquisition Guidebook, and the DoD Product Support BCA Guidebook. While aggregated LCI results are used for LCIA, costs must be tabulated by the year in which they occur for LCC.

3.3.1 Internal Costs

This step incorporates and supplements existing DoD policies for estimating internal LCC (i.e., those incurred by DoD). As a starting point, the costs identified as part of the LCI step (Step 2) should be used to develop an initial LCC estimate. Additional costs that would or could be incurred by DoD, but are generally overlooked or not accounted for using existing cost element structures, will likely be identified when estimating the physical inputs and outputs (Step 2), the associated life cycle impacts (Step 3), and the resulting external costs (described above). This section provides guidance on identifying and aggregating these sustainability-related costs into the internal LCC estimate.

- **Identify activities with hidden costs.** The assessment of impacts and external costs may reveal internal DoD direct and indirect costs not identified in the initial LCC estimate. For example, hidden costs can be associated with risk mitigation (e.g., engineering controls, personnel protection equipment, medical monitoring, regulatory permits, and waste management). They can also be associated with resource consumption (e.g., resource use during sustainment, additional labor requirements, and transportation of resources). Focus should be placed on identifying indirect costs, which are often aggregated into overhead costs at the installation, command, or Service level but should be allocated to the system for a more refined estimate of the system's LCC.
- **Align costs to existing DoD cost elements**. While established, cost element structures may not adequately support the LCC introduced in this guidance. In such cases, analysts will be required to place these additional internal costs into the standard cost element structures customarily used in LCC estimation. For better integration into each alternative's LCC estimate, internal hidden and contingent costs should be grouped into existing DoD cost elements when applicable.
- **Collect cost data** for costs that have not already been captured using the same process described in the LCI step.
- **Integrate hidden costs into LCC estimate**. As with the initial LCC estimate, all hidden cost estimates should be developed and integrated into the system LCC estimate in accordance with established DoD and relevant federal cost estimating policies, instructions, and guidance.
- **Calculate the net present value (NPV)** of each alternative using the real discount rate obtained from OMB Circular A-94.

Notional Sustainability Analysis – LCC Estimating – Inclusion of Escalation Rates

Many commodities change at rates different than general inflation. Cost estimates that forecast funding requirements for weapons systems often incorporate escalation rates to account for this discrepancy. Because escalation rates differ from inflation, a decision must be made for which inputs and outputs require an escalation factor for cost estimation. The figures in Section 3.1.5 illustrate hypothetical system boundaries for comparing two alternative noncombat ship superstructures, including inputs and outputs associated with each alternative. A simplified cost estimate incorporating escalation rates is shown below.

First, the cost of the inputs and inputs in the base year must be estimated. Escalation factors are found for inputs and outputs. In this case, cost factors[14] from this guidance's appendix were chosen, which are categorized by industry sector (i.e., using NAICS codes). A real inflation rate of 2.2% was used in accordance with OMB Circular A-94, Appendix C. Cash flows (CF_n) for years 2016–2020 are calculated by multiplying the previous year's cash flow (CF_{n-1}) times the inflation rate (π) times the escalation factor (e). It should be noted that the factor used in the following formula represents real price change with respect to inflation over a year.

$$CF_{n+1} = CF_n * \pi * e$$

The NPV can then be estimated using the following formula. Each year's net cash flow is represented by 'CFt' and the number of periods is represented by 't.'

$$PV = \sum_{t=1}^{n} \frac{CF_t}{(1+\pi)^t}$$

Inputs & Output	(Escalation) Inflation Factor	Internal Cost ($)						
		NPV	2015 (base year)	2016	2017	2018	2019	2020
Fuel	1.000	$ 16,313,101	2,868,882	2,868,882	2,868,882	2,868,882	2,868,882	2,868,882
Water	1.030	$ 6,083	1,012	1,035	1,059	1,083	1,107	1,132
Cleaning Agent	0.989	$ 17,046,024	2,842,739	2,904,570	2,967,745	3,032,295	3,098,249	3,165,637
Fuel	1.000	$ 18,421,862	3,239,736	3,239,736	3,239,736	3,239,736	3,239,736	3,239,736
Water	1.030	$ 26,359	4,386	4,485	4,587	4,691	4,797	4,906
Cleaning Agent	0.989	$ 73,866,104	12,318,535	12,586,469	12,860,230	13,139,945	13,425,745	13,717,760

The example table below illustrates the impact of use of escalation rates. Each escalation rate example (one per row) assumes an initial $1000 cost. The first row uses the inflation rate, while the second assumes an escalation rate higher than that of inflation and the third row assumes an escalation rate lower than inflation.

(Escalation) Inflation Factor	NPV	2015 (base year)	2016	2017	2018	2019	2020
1.000	$ 5,789	$ 1,000	$ 1,022	$ 1,022	$ 1,022	$ 1,022	$ 1,022
1.030	$ 6,086	$ 1,000	$ 1,023	$ 1,054	$ 1,086	$ 1,119	$ 1,153
0.989	$ 5,683	$ 1,000	$ 1,022	$ 1,010	$ 999	$ 987	$ 976

[14] DoD Sustainability Assessment Guidance - Appendix I Scoring Factors. Retrieved from: https://www.denix.osd.mil/esohacq/home/

3.3.2 Contingent Costs

- **Identify activities with contingent costs**. The assessment of impacts and external costs may reveal possible future events (e.g., regulatory changes, material non-availability, substitute material testing) that would result in additional internal costs to DoD. For example, a hazardous material could be restricted due to future regulatory actions, resulting in additional costs to qualify and implement a replacement substance. Equipment controls or personal protective equipment could fail, resulting in additional costs due to injury or illness to DoD personnel.
- **Estimate contingent costs**. Contingent costs are the valuation of a system's embedded risk. Risk has two (2) components: the probability an event will occur; and the consequences associated with the event. For many sustainability-related risks, neither of these components are well-defined, making it difficult to estimate the associated cost. Sensitivity analysis, uncertainty analysis, and scenario-based methods can be used to estimate the range of possible contingent costs. Although considered a type of internal cost, contingent quantify the risk embedded in a system acquisition and therefore should not be summed with internal costs.

3.4 Step 3 – Estimate Life Cycle Impacts

Once the LCI has been created, the next step is to estimate the potential impacts to resource availability, climate change, human health, and ecosystem quality. Within LCA, a process called life cycle impact assessment (LCIA) uses characterization models to estimate the contribution of each inventory flow on each impact category considered.

3.4.1 Cause-Effect Models

Several LCIA methods are available in the public domain (e.g., Bare et al., 2003; Bulle et al., 2019; Huijbregts et al., 2017); this SA Guidance does not specify which model to use. These LCIA methods assess the potential impact from using resources or releasing substances to the environment at different points of the cause-effect chain as illustrated in Figure 12.

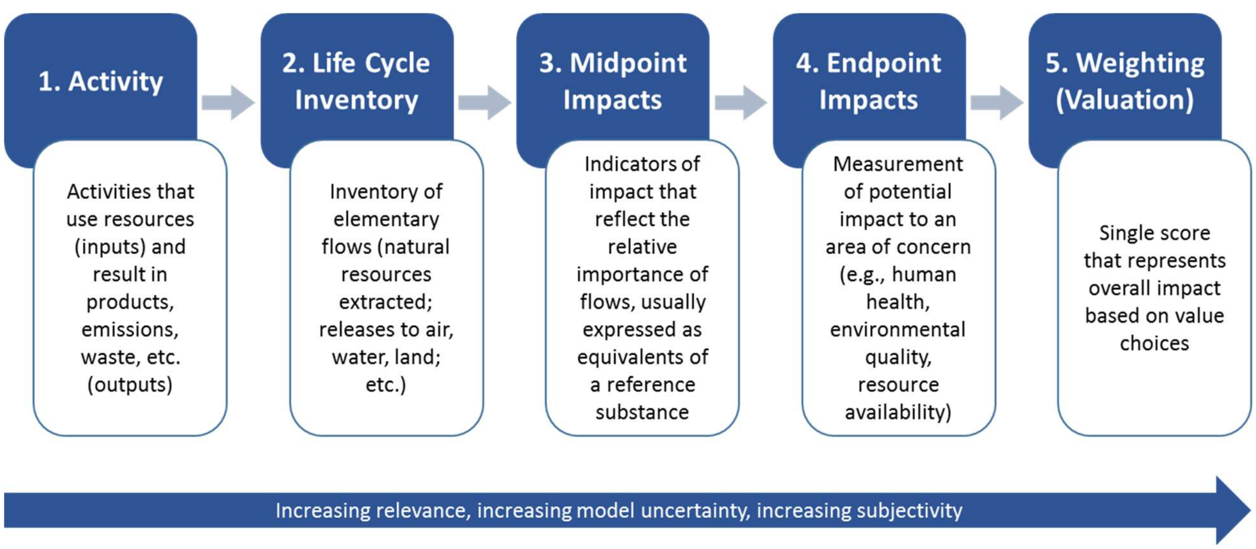


Figure 12. Use of Cause-Effect Models in Life Cycle Impact Assessment

1. An **activity** uses inputs and generates outputs.

2. The **LCI** aggregates these inputs and outputs to generate an inventory of elementary flows (i.e., resources used from the environment and releases to the environment).
3. **Midpoint characterization factors** are used to estimate midpoint impacts, which are indicators of potential impact. Each midpoint impact category is measured in equivalence of a reference substance, resulting in disparate units that cannot be combined for an overall assessment. Midpoint impacts enable identification of specific tradeoffs between alternatives; however interpretation requires knowledge of diverse environmental issues and it can be difficult to prioritize the tradeoffs.
4. **Endpoint characterization factors** are used to estimate endpoints impacts, which represent potential impact (or damage) to resource availability, climate change, human health, and ecosystem quality. Results are expressed in units of damage, which are easier to interpret and can be aggregated. This makes it easier to understand the relative importance of impacts and compare alternatives.
5. **Weighting factors** are used to aggregate impacts into a single score expressed in the same unit. The DIO method performs weighting using monetary valuation, which converts potential environmental impacts into monetary units based on the associated external cost to society.

Moving from left to right on the cause-effect chain, the results are aggregated into fewer impact categories, it is easier to make comparisons between alternatives, and the relevance of the impacts are easier to understand. However, uncertainty and subjectivity increase. Due to this uncertainty and subjectivity, the ISO LCA standards require that weighting results only be considered in combination with endpoint, midpoint, or inventory results. Midpoint and endpoint impacts are calculated as part of this step. Valuation is performed in the next step.

Figure 13 provides an example cause-effect chain for estimating impacts from toxic release to air. Midpoint characterization factors are used to quantify the inventory of toxic releases in comparative toxic units – and indicator of increased morbidity in humans due to increased exposure to toxic chemicals. Endpoint characterization factors are used to quantify the potential damage to humans in disability-adjusted life years from exposure to the toxic chemicals. Monetary valuation is used to weight the impacts by assigning monetary value to the human health degradation (i.e., life years lost).

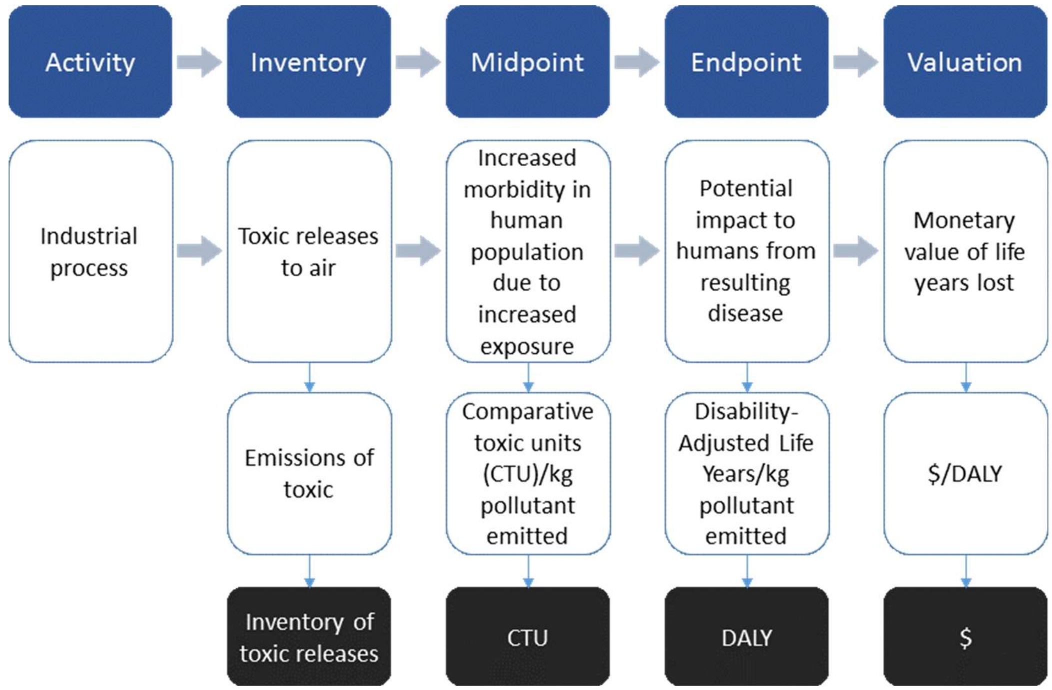


Figure 13. Example Cause-Effect Chain for Estimating Impacts from Toxic Release to Air

3.4.2 Midpoint Categories

When performing a Sustainability Analysis, the following impact categories should be used:

- **Climate change**. When released into the atmosphere, greenhouse gases (GHGs) absorb and re-emit radiation, causing heat to be retained in the atmosphere, and thereby contributing to an increase in the global average temperature and the associated changes in global climate patterns. This impact category serves as an indicator of impacts from greenhouse gas emission. In general, the potency of greenhouse gases is assessed relative to that of carbon dioxide (CO2) and are reported as CO2 equivalents, also referred to as global warming potentials (GWPs).
- **Human health**. Serves as an indicator of impacts to humans from resource usage and environmental releases. The category is often subdivided into subcategories that represent different types of effects on human health. Example subcategories include toxic chemicals contributing to carcinogenic effects; toxic chemicals contributing to non-carcinogenic effects; inorganics contributing to respiratory effects; and organics contributing to respiratory effects.
- **Ecosystem quality**. Serves as an indicator of impacts to ecosystems from resource usage and environmental releases. This category is often subdivided into subcategories that represent different types of effects on ecosystem quality. Example subcategories include acidification (increased environmental acidity); eutrophication (increased nutrient loadings in aquatic systems); and toxic chemicals contributing to ecotoxicity.
- **Fossil energy use.** Serves as an indicator of resource availability from depleting fossil fuel resources from the earth.
- **Mineral use**. Serves as an indicator of resource availability from depleting mineral resources from the earth.
- **Land use.** Serves as an indicator of environmental impacts from land use and transformation.

- **Water use**. Serves as an indicator of water stress, environmental, and human health impacts from using water resources.

If any of the midpoint categories listed above are omitted, reasons for their omission should be explained.

3.4.3 Endpoint Categories:

When performing a Sustainability Analysis, the following impact categories should be used:

- **Resource availability**. Characterizes the potential impact to resource availability from using fossil energy and minerals.
- **Climate change**. Characterizes the potential damage to human health and ecosystems from global warming.
- **Human health**. Characterizes the potential damage to human health from relevant impacts (e.g., carcinogenic effects due to toxic chemicals; non-carcinogenic effects from toxic chemicals; respiratory effects from inorganics; respiratory effects from inorganics; noise; and water use).
- **Ecosystem quality.** Characterizes the potential damage to ecosystems from relevant impacts (e.g., acidification; eutrophication; ecotoxicity; water use; and land use).

If any of the endpoint categories listed above are omitted, reasons for their omission should be explained.

3.4.4 External Costs

Economic valuation is used to monetize the associated externalities (i.e., costs incurred by society outside of DoD as a consequence of the life cycle impacts). Economic valuation methods assign monetary value based on people's utility (e.g., satisfaction or welfare) from or willingness to pay for a service (e.g., ecosystem services, health).[15] The DIO method uses external costs factors derived for a specific year.[16]Recall that all monetary flows from the LCI were normalized to the reference year. The following steps are based on using the DIO tools:

- **Calculate external cost** by multiplying the input and output data collected above by their external cost factors for each impact category. When using the scoring factors, the user identifies the row that represents each input and output and multiplies the quantity of input or output by the scoring factors. When using the web-based tool or the DIO dataset with LCA software, this step is automated. While impacts are aggregated across the life cycle, external costs must be tracked by the year in which they occur.
- Calculate the present value of the external costs using the social discount rate.
- **Normalize external cost** to the study reference year. If the study reference year occurs after the reference year of the DIO tool, external costs should be inflated to the study reference year. If the study reference year occurs before the reference year of the DIO tool, external costs should be discounted to the study reference year. While this allows for the evaluation of internal and

[15]Additional guidance on using economic valuation is provided in the Office of Management and Budget (OMB) Circular A-4 (US OMB 2017), which provides guidance to Federal agencies on the development of regulatory analysis, and the U.S. Environmental Protection Agency (EPA)'s "Guidelines for Preparing Economic Analyses" (US EPA 2014).

[16] The first release of the DIO dataset gives results in USD2014. Future releases may use a different reference year.

external costs in the same monetary terms, the internal and external costs estimates should not be aggregated.

3.4.5 Approach for Estimating Life Cycle Impacts

There are a number of published LCIA methods. To ensure consistency with other Sustainability Analyses conducted within DoD, it is recommended that the impact assessment method provided by the DIO dataset be used, via the scoring factors, web-based tool, or dataset provided on DENIX. If a different life cycle impact assessment method it used, the method and reasons for using it should be explained. The following steps are based on using the DIO tools:

- **Calculate impacts** for each impact category. This is accomplished by multiplying the input and output data collected above by their characterization factors for each impact category. When using the scoring factors, the user identifies the row that represents each input and output and multiplies the quantity of input or output by the scoring factors. When using the web-based tool or the DIO dataset with LCA software, this step is automated.
- **Group impact results** to enable a better understand the components of the system that drive overall environmental impact. For example, impact results are often presented by life cycle stage, organization, activity, and elementary flow. For the Sustainability Analysis, impact can be grouped by supply chain, prime OEM, DoD, and sustainment contractor.

3.5 Step 5 – Synthesize Results and Iterate

Sustainability Analysis results should be interpreted and synthesized to support the goals of the study. The interpretation of results should help decision-makers understand the relative importance of impacts, activities that drive cost and impact, the level of confidence in the results, and important limitations. A Sustainability Analysis is an iterative process. The results in later steps often reveal data gaps that can be re-addressed in earlier steps. Within time and resource constraints, the Sustainability Analysis should be updated when new data become available. Such updates may include altering the system boundary for improved comparability between alternatives, updating life cycle activity and cost profiles, and refining impact and cost results.

Throughout the Sustainability Analysis, the following evaluations should be performed:

- ***Consistency check***: Assumptions, methods, and data used in the LCA should be clearly documented. A consistency check should be conducted to confirm that the analysis supports the specified Sustainability Analysis goals and scope, is complete, does not contain inconsistencies, and is based on realistic assumptions.
- ***Completeness check***: Omissions and data gaps should be clearly identified. Examples include activities for which data is not available, exclusion of an impact category, or materials and chemicals released to the environment for which characterization factors do not yet exist. When characterization factors do not exist for a substance released to the environment, the substance is included in the inventory, however, it is characterized as having no impact. Based on identified omissions and data gaps, it should be determined if the available information and completed analysis are sufficient for reaching conclusions.
- ***Data quality assessment***: Throughout the Sustainability Analysis, aspects of data that may reduce confidence in the results, and their ability to inform decisions, should be documented. Example aspects include data source, data accuracy, data age, technological representation, temporal

representation, and geographical representation. Upon completion of the analysis, an assessment should be made to identify data quality concerns and their potential impact on results.

- ***Sensitivity and uncertainty analysis***: To the extent possible, uncertainty in Sustainability Analysis results should be identified, quantified, and reported. At a minimum, sensitivity analysis should be employed to determine which parameters drive the majority of uncertainty in the results, assess the sensitivity of results to changes in assumptions, in particular those with the highest level of uncertainty and variability, and assess the relative importance of data gaps. When possible, uncertainty analysis should be conducted to describe the range of possible results.
- ***Contribution analysis***: Life cycle stages and individual activities which are significant contributors to overall impact should be identified for midpoint impacts, endpoint impacts, internal costs, external costs, and contingency costs.
- ***Comparison of alternatives***: Alternatives can only be compared side-by-side if the system boundaries, assumptions, context, system performance, data quality, and modeling approach are equivalent. When comparing alternatives, any differences between the systems and associated models must be clearly explained. Comparisons should be provided for important LCI and midpoint results and for all endpoint and valuation results.

4 Reporting Requirements

The results of the Sustainability Analysis should be presented to identify activities that drives life cycle impact and LCC, and compare alternatives. At a minimum, results should be presented for the following:

- **Scope**: The system descriptions, functional unit, and system boundaries should be clearly documented. When available, a diagram illustrating the system boundaries should be provided.
- **LCI data**: The inputs (e.g., procured goods, procured services, and other resources) and outputs (e.g., air emissions, water releases, land releases, solid waste, hazardous waste, wastewater, and noise) identified for each activity in the system boundary should be documented. To the extent possible, data sources should be clearly identify and data quality evaluated. Standards for format of LCI data and metadata have been created by the Federal LCA Commons.
- **LCI results**: If there are specific elementary flows (i.e., resources coming directly from the environment and releases to the environment) that drive impacts or costs, information about these elementary flows can be provided to identify the responsible life cycle stages or activities.
- **Midpoint impacts**: Midpoint impacts provide the analyst with a clear understanding of the relative potency, in terms of physical units, of each system's aggregated outputs. Midpoint results can be used to inform decision decisions and identify tradeoffs between alternatives. All midpoint impacts should be reported for each alterative considered.
- **Endpoint impacts**: Endpoint impacts quantify the overall damage, in physical units, that could occur as a result of the system's aggregated impacts. Although additional assumptions are needed to calculate endpoint impacts, endpoints can be valuable when communicating the expected damage that a system could cause over its life cycle. All endpoint impacts should be reported for each alternative considered.
- **Internal LCC**: The internal LCC estimate for each alternative should be reported.
- **External LCC**: External cost is an indicator of an impact's overall importance. External LCC should be reported for each alternative considered. They should not be aggregated with internal LCCs.
- **Contingent cost**: Contingent costs are the valuation of a system's embedded risk. High contingent costs may highlight a cost-based risk that may be passed on the sustainment community. Contingent cost should be reported for each alternative considered. Like external cost, they should not be aggregated with internal cost.

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Glossary

Allocation: Partitioning the input or output flows of a specified activity within the system boundary between the product system under study and one or more co-products.

Characterization: The translation of elementary flows into potential impact for each impact category.

Characterization factor: A conversion factor used in the DoD Sustainability Analysis methodology to convert an elementary flow to an impact. Characterization factors are derived from life cycle impact assessment models.

Chemical: A substance produced by or used in a chemical process. A chemical is any element, chemical compound, or mixture of elements or compounds. Chemicals are the constituents of materials. A chemical “mixture,” also known as a chemical “preparation,” includes multiple chemicals.

Classification: assignment of elementary flows in the LCI to the impact categories for which they have an impact. Some elementary flows contribute to multiple impacts, and will therefore be assigned to multiple impact categories.

Climate change: Includes greenhouse gas emissions, their contribution to global warming, and the associated impacts, including changes in net agricultural productivity, human health, property damages from increased flood risk, and ecosystem services.

Contingent cost: Costs that might occur in the future as a result of decisions made today or as a result of future events (e.g., litigation, site remediation, hospitalization, disability, increased cost, or unavailability of resources). These costs are based on assumptions that are different from the baseline and have associated probability distributions. These costs are classified as a type of internal cost to the DoD.

Co-product: One or more usable outputs, in addition to the reference flow, resulting from the same activity.

Cost element: One of many cost items that make up a cost estimate.

Cost element structure: Describes and defines the specific elements to be included in a cost estimate.

Cost Factor: An indexed unit that allows the analyst to quickly estimate the external cost for a given impact category by multiplying that factor by inventory data. A cost factor assesses supply chain, natural resource use, release, or activity costs. Supply chain cost factors assess upstream external costs. Natural resource use and release cost factors assess downstream external costs. Activity cost factors are a hybrid and assess both upstream and downstream external costs.

Deployment: A life cycle stage of the Production & Deployment Phase in the Integrated Defense Acquisition, Technology, and Logistics Life Cycle Management System that falls within the Sustainability Analysis study boundary discussed in this guidance.

Disability Adjusted Life Year (DALY): A measure of overall disease burden, expressed as the number of person-years lost due to ill-health, disability, or early death. The DALY relies on an acceptance that the most appropriate measure of chronic illness impact is time; both time lost due to premature death and time spent disabled by disease.

Disposal: A life cycle stage of the O&S phase in the Integrated Defense Acquisition, Technology, and Logistics Life Cycle Management System that falls within the Sustainability Analysis study boundary discussed in this guidance. Disposal (end-of-life) management activities include decommissioning, demilitarization, disposal, re-using, re-purposing, recycling, incinerating, and land filling.

Downstream: Activities and processes that occur during the manufacture, operation, sustainment, and disposal of the system. While an OEM supplies a manufactured system to DoD, for the purpose of a Sustainability Analysis, the OEM will be treated as an extension of the DoD.

Ecosystem Quality: Includes environmental releases, land use, and water use, and the associated impacts on biodiversity and ecosystem services.

External cost: Costs borne by society or organizations outside of DoD as a result of pollutant releases, waste disposal, degradation to human health and ecosystem quality, or resource use during the lifetime of the system.

External cost factor: An indexed unit that assigns a standardized monetary value of all relevant external costs associated with an inventory item.

Environmentally Extended Input-Output Analysis: Relates economic activity from economic I-O models to resource consumption and environmental releases for each sector to estimate supply chain impacts from purchased goods and services.

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 Sustainability Analysis results across alternative systems. For a further explanation please see ISO 14040 and 14044.

Global Warming Potential: A relative measure of how much energy a greenhouse gas traps in the atmosphere, relative to how much energy carbon dioxide traps in the atmosphere. The higher the global warming potential, the more the gas warms the earth as compared to carbon dioxide.

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.

Hidden costs: Internal DoD costs not identified in a cost estimate. Many of these costs are often aggregated into overhead costs at the installation, command, or Service level but should be allocated to the system for a more refined estimate of the system's LCC.

Human Health: Includes environmental releases, water use, and noise emissions, and the associated impacts on human health and productivity.

Hybrid life cycle assessment: A LCA that connects process-based LCA and EEIO analysis to reduce truncation error by expanding the system boundaries of an LCA to include extended supply chain impacts.

Impact category: A standalone category representing a potential impact to the resource availability, climate change, human health, or ecosystem quality resulting from a system's LCI. 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).

Impact Factor: An indexed unit that allows the analyst to quickly estimate the level of impact for a given impact category by multiplying that factor by inventory data. An impact factor assesses supply chain, natural resource use, release, or activity impacts. Supply chain impact factors assess upstream impacts. Natural resource use and release impact factors assess downstream impacts. Activity impact factors are a hybrid and assess both upstream and downstream impacts. Impact factors may assess midpoint or endpoint impacts.

Indirect cost: Overhead costs tracked at a facility level and not allocated to a particular system.

Input: Items required to complete a process or activity (e.g., resources, procured items and services, labor).

Integrated Product Support Elements: The package of support functions required to deploy and maintain the readiness and operational capability of major weapon systems, subsystems, and components, including all functions related to weapon systems readiness. IPS Elements are functional components of a weapon system's product support infrastructure. These elements support sustainment planning and execution throughout a system's entire life cycle, translating force provider capability and performance requirements into tailored product support.

Internal cost: Costs borne by the DoD during the lifetime of the system. These costs include direct costs (e.g., materials, fuel, labor), indirect costs (e.g., overhead) and contingent costs (e.g., costs resulting from future events that may or may not occur).

Inventory data: A category of system inputs (energy, chemicals, materials, water, and land) or outputs (chemical and noise releases) that occurs within the system boundary.

Life cycle assessment (LCA): The compilation and evaluation of the inputs, outputs, and the potential impacts to human health and the environment of a system throughout its life cycle. LCA is a technique used to assess the environmental aspects and potential impacts associated with a product, process, or service, by (1) compiling an inventory of relevant energy and material inputs and environmental releases, (2) evaluating the potential environmental impacts associated with identified inputs and environmental releases, and (3) interpreting the results to inform decision-making.

Life cycle cost (LCC): For a defense acquisition program, LCC consists of Research and Development (R&D) costs, investment costs, operating and support costs, and disposal costs over the entire life cycle. These costs include not only the direct costs of the acquisition program, but also indirect costs that would be logically attributed to the program. The LCC may be referred to as Total Ownership Cost.

Life cycle cost estimate: A result or product of an estimating procedure that specifies the expected dollar cost required to research and develop, test, product, operate, sustain, and dispose of a system.

Life Cycle Inventory (LCI): An LCI 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.

Life Cycle Impact Assessment (LCIA): The LCIA phase of an LCA is the evaluation of potential human health and environmental impacts of the environmental resources and releases identified during the LCI. Impact assessment addresses ecological and human health effects, as well as resource depletion. A life cycle impact assessment attempts to establish a linkage between the system or process and its potential impacts.

Material: Anything that serves as crude or raw matter to be used or developed. A material is the basic matter (as metal, wood, plastic, fiber) from which the whole or the greater part of something physical (as a machine, tool, building, fabric) is made. Chemicals are the constituents of materials. For example, human-made materials like petroleum-based plastics are synthesized from chemicals.

Monetization: The assignment of monetary value to the associated externalities using economic valuation methods, which assign monetary value based on people's utility (e.g., satisfaction or welfare) from or willingness to pay for a service (e.g., ecosystem services, health).

Noise: Unwanted or disturbing sound above ambient levels.

Office of Cost Assessment and Program Evaluation (CAPE): CAPE provides independent analytic advice to the Secretary of Defense on all aspects of the Defense program, including alternative systems and force structures, the development and evaluation of defense program alternatives, and the cost-effectiveness of defense systems.

Operations and Support (O&S): A life cycle phase in the Integrated Defense Acquisition, Technology, and Logistics Life Cycle Management System that falls within the Sustainability Analysis study boundary discussed in this guidance. This phase includes activities such as system operations, support for the system, sustainment, and disposal.

Original equipment manufacturer (OEM): A company that develops and produces military systems.

Output: Products, co-products, waste, emissions to air, discharges to water and soil, and other environmental releases that are generated by a process or activity.

Process-based life cycle assessment: A bottom-up approach in which input and output data are collected for every activity across a systems life cycle.

Production: A life cycle stage of the Production and Deployment phase in the Integrated Defense Acquisition, Technology, and Logistics Life Cycle Management System that falls within the Sustainability Analysis study boundary discussed in this guidance.

Raw material acquisition: A life cycle stage typically included within LCA, and sometimes Sustainability Analysis. Raw material acquisition includes harvesting and processing natural resources from the environment.

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

Reference flow: The amount of output from an activity or process required to fulfill the system's functional unit.

Reference year: The year to which all costs are normalized.

Release: The introduction of an item (e.g., a hazardous substance, noise) to the environment.

Release 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 a release factor provides a quantitative measure of the expected intensity of releases 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.

Release profile: An estimated inventory of the quantity of all chemical compounds emitted during a specified activity. When applicable, equipment controls that reduce the total quantity of releases (e.g., air filtration) should be accounted for when developing a release profile.

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.

Residual value: The remaining value of a system or component at the end of study life span or of materials that will be recycled or reused. Residual value is calculated using a specified depreciation schedule. When a depreciation schedule is not specified, Straight Line Depreciation is used. For materials that are recycled or reused, the value of materials on a secondary materials market represents the residual value.

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

Resource: Basic materials or energy drawn from the environment.

Resource availability: Includes natural resource use (e.g., land, water, mineral, and fossil resources), potential impacts on resource quality and availability, and the associated marginal cost increase.

Scoring factor. An estimate of the potential environmental impact or external cost per unit procured good or service, activity, or elementary flow.

Study period: The number of years the Sustainability Analysis is based on.

Sustainable acquisition: Acquisition conducted in a manner that results in a system design that minimizes negative impacts on resource availability, climate change, human health, and ecosystem quality while meeting performance parameters.

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.

Sustainable alternative: An option that meets all performance requirements outlined in the Initial Capabilities Document, the Capability Development Document, or component performance specifications; minimizes negative impacts to resource availability, climate change, human health, and ecosystem quality; and has a lower total ownership cost.

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 Life Cycle Costing, which captures LCCs of a system, product, or process.

Sustainability-related cost: Any cost (internal, external, or contingent) over a system's life cycle that is associated with the consumption of resources or the resulting impacts from such consumption, as identified by a Sustainability Analysis. Sustainability-related costs and sustainment costs are intertwined. These costs are typically hidden and not allocated to a system under traditional cost accounting methodologies (e.g., personal protective equipment, medical monitoring, permitting). A Sustainability Analysis helps uncover additional sustainability-related costs that may not have been considered using traditional sustainment costing methods.

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

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.

Supply chain: The organizations and processes that provide procured goods and services.

Support system: Any system or subsystem that supports the system of interest in a manner that ensures that the function is met.

Support activity: Any activity tied to a specified support system that falls within the established system boundary.

System: Any weapon system, equipment, or platform acquired by the DoD to achieve a capability requirement, as defined by the ICD or CDD.

System activity: Any activity that occurs within the established system boundary and necessary to meet the requirements of the functional unit.

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

Total Ownership Cost (TOC): See Life Cycle Cost.

Truncation error: Omission of life cycle activities, often from the supply chain, from a LCA or LCC estimate.

Upstream: Activities occurring prior to those conducted by the organization conducting the Sustainability Analysis. In general, upstream includes the organization's supply chain.

Valuation: The assignment of monetary value to potential environmental impact based on the economic value of the associated externalities (i.e., costs incurred by society as entities outside of DoD as a consequence of the life cycle impacts).

Waste: Substances or objects (hazardous or non-hazardous) that are outputs of the system and require waste management services such as disposal or recycle.