LIFE CYCLE COST HANDBOOK

Guidance for Life Cycle Cost Estimation and Analysis

Office of Acquisition and Project Management
U.S. Department of Energy
Washington, DC

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Contents

FOREWORD

This handbook provides procedures, information, examples, and tools to develop consistent and defensible life-cycle cost estimates (LCCE) and perform appropriate life-cycle cost analyses (LCCA) for capital projects. The handbook is generic and is applicable to all Department of Energy (DOE) elements; however, it may provide tailored guidance for a specific program office. It provides references and tools that can be used, and references existing requirements in other documents that must be met.

This handbook is not a requirements document and should not be construed as a requirement. It is intended to provide a consistent approach based on best practices to support the development of effective and credible LCCEs. It is primarily based on guidance and best practices from the Government Accountability Office (GAO) regarding development of high-quality estimates, the Association for the Advancement of Cost Engineering International (AACEI), and other reputable industry sources. DOE programs and projects may use alternative methodologies or tailored approaches more suitable to their types of projects and technologies as appropriate.

This handbook is intended to be a living document. Comments (recommendations, additions or deletions) and pertinent data that may be of use in improving this document should be forwarded to the Department of Energy, Office of Acquisition and Project Management, Attention: MA-63, 1000 Independence Ave. SW, Washington, DC, 20585.

1.0 INTODUCTION

1.1 Requirements

Life-cycle costs are an important consideration for all DOE projects and programs. Reliable life-cycle cost estimates (LCCE) and life-cycle cost analyses (LCCA) are critical functions for supporting DOE management decision-making, program planning, and alternative selection processes. The estimates are important for communicating expectations and requirements to the Office of Management and Budget (OMB), Congress, the Government Accountability Office (GAO), and other external stakeholders.

DOE O 413.3B, *Program and Project Management for the Acquisition of Capital Assets*, establishes the framework for project selection at Critical Decision 1 (CD-1) as choosing the alternative that "provides the essential functions and capabilities at an optimum life-cycle cost." Thus, realistic LCCEs are needed to support the CD-1 selection of a project from a range of possible alternatives and the techniques used to compare life-cycle costs of a range of alternatives must be sound and well documented.

DOE O 413.3B defines life-cycle costs as "the sum of all direct, indirect, recurring, nonrecurring, and other related costs incurred in the planning, design, development, procurement, production, operations and maintenance, support, recapitalization, and final disposition of real property over its anticipated life span for every aspect of the program, regardless of funding source." [1]

Beyond CD-1, LCCEs and the use of those estimates for analysis of alternatives, remain an important element to support value engineering efforts during project development and definition and even during project execution. LCCEs are needed for effective out-year budget planning and subsequent budget requests. The estimates should be updated as new data become available or when plans, assumptions, etc., change.

As with projects, programs should appropriately identify and consider life-cycle costs as part of the long-range planning and portfolio selection and management processes.

The OMB requires LCCEs as part of budget submissions for capital assets related to information technology (IT) investments (Exhibits 53 and 300 submittals), and also emphasizes the need for value engineering (in accordance with Circular A-131) which requires realistic estimates and analyses of life-cycle costs. OMB Circular A-94 provides guidelines and discount rates to use for benefit-cost analysis of federal programs.

Beyond these general requirements, Congress often specifically mandates appropriation-related language requiring DOE submission of LCCEs and alternative selection criteria.

[1] This is the definition found in DOE O 413.3B; however, note that the LCC also includes all efforts related to construction and renovation.

It is the intent of this handbook to provide the DOE community with LCC guidance, tools, and references to comply with the requirements and support project development and selection decisions.

1.2 Background

The LCCE and LCCA provide critical management insight to the costs and resources, both near- and long-term that will be required to accomplish a project or program. They provide a more comprehensive estimate of the true costs of a project or program than an estimate that only captures the project execution phases. The life-cycle phases of a project or program within DOE generally consist of the following generic phases, as applicable:

Phase 1: Mission need assessment
: From a capital asset project perspective, this includes all activities required to be accomplished before CD-0 approval and creation of a project.

Phase 2: Alternative studies and analyses
: From a capital asset project perspective, this includes all activities required to be accomplished before CD-1 approval.

Phase 3: Design
: This phase includes all preliminary and final design efforts, together with any ancillary efforts or support needed during the design phase, for project or program implementation. This phase includes both CD-2 and CD-3 efforts for capital asset projects.

Phase 4: Procurement and construction
: This phase captures all costs needed to complete a project through CD-4 approval that have not been previously captured in the phase 3 activities.

Phase 5: Operations and maintenance
: This phase, if applicable, captures all costs from completion of the capital asset project through the end of the useful life of a facility or program. It includes the operations and maintenance of facilities and infrastructure, as well as production- or program-related operations and the necessary supporting functions such as safeguards and security. Also included in this phase are any needed replacements and upgrades over the life of the project/program.

Phase 6: Surveillance and long-term maintenance
: This phase, if applicable, represents those efforts that will be carried out after operations cease, but before a final disposition is determined and/or carried out. Surveillance and maintenance (S&M) would typically be initiated by and therefore include a deactivation and associated stabilization effort as well.

Phase 7: Final Disposition
: Final Disposition may include any combination of mothballing (if nothing further is ever planned to be done), decontamination, demolition, return of site to grassroots or other condition, etc.

The first four phases are addressed by DOE O 413.3B for capital asset projects, with the demarcation between phases generally represented by Critical Decision points. The remaining three phases, while governed by other appropriate DOE orders, are less well structured or supported by estimating and analytical guidance within DOE. This handbook should help to fill that void.

There may be differences in life-cycle phases and coverage among the various DOE program offices and types of projects or programs. In particular, the phases typically encountered for environmental management (EM) and environmental restoration (ER) projects are very different from the phases seen for design, construction, and operation of the more typical DOE facility (new or modification). Appendix A of this manual relates the above described traditional life-cycle phases to those encountered by EM/ER projects within DOE.

To clearly illustrate the LCC principles and guidance recommended for all of DOE in this handbook, the above general structure will be used throughout this document for consistency. The principles presented are equally applicable, even for situations where phases may be viewed somewhat differently depending on program-specific requirements and approaches.

Although the basic concepts and guidance presented in this handbook are universally applicable, where needed, this handbook makes distinctions between projects and programs as they apply to LCCE and LCCA. Life-cycle phases for programs are naturally different from those specified for projects. But every program should ensure that the phases identified and used therein appropriately capture the full life cycle of the program in question.

<u>Establishing Boundaries for LCC</u>

Life-cycle cost as defined in this handbook does not cover everything from cradle to grave. Rather, it is discussed in terms of the earliest activity to be included in the LCC scope to the latest. Within DOE, the LCC begins with the mission needs assessment (those activities that lead to eventual approval of a capital asset project at CD-0) and extends past the completion of the capital asset project through the life of the project or facility, ending with the completion of the appropriate final disposition for the project.

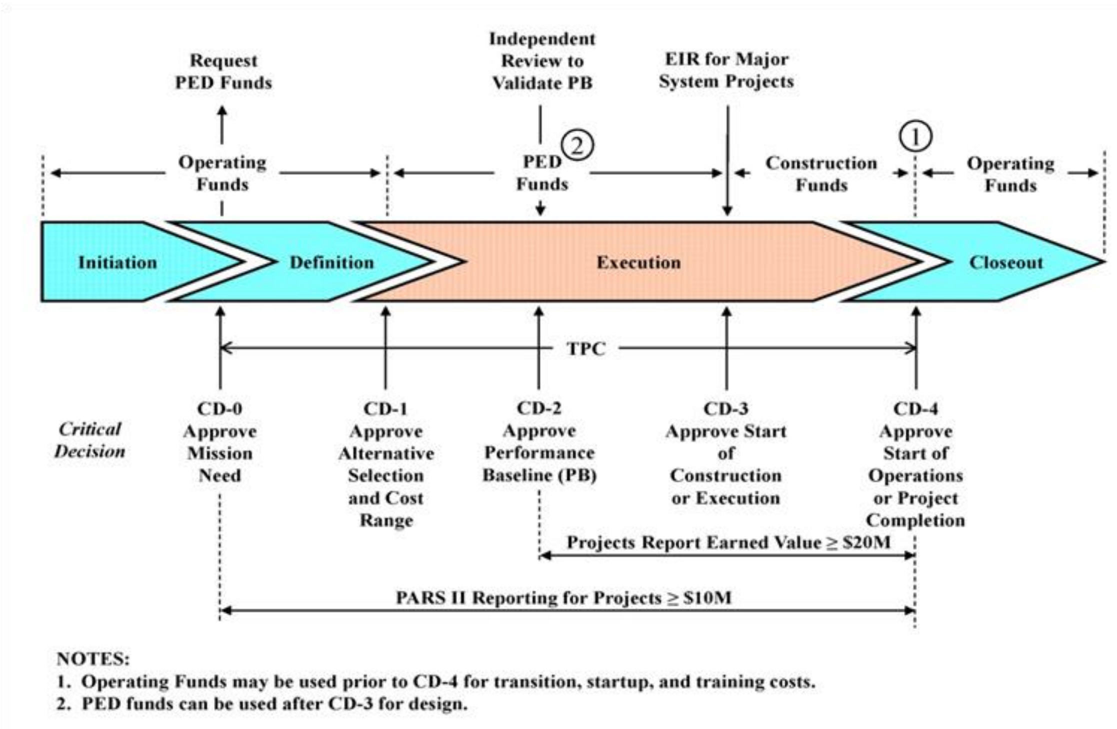
There may be situations where the LCC scope for a particular project is defined even more narrowly, such as when a liability is transferred from a project or program to another program that will be responsible for the “final disposition” (e.g., transfer to legacy management). That would be the case when LCC is being viewed from a programmatic perspective. Also, projects or programs do not extend to eternity, and the handbook recognizes that a project or program will have a defined end even when liability remains with the program after work activities cease.

Depending on the timing of an LCCE or LCCA and on the intended purposes of those efforts, the actual costs incurred for previously completed or underway phases must be captured and included for the LCCE or in an LCCA. If the effort is only intended to evaluate alternative scenarios going forward, those “sunk” costs may not be relevant and can be appropriately excluded; however, the accompanying documentation should clearly describe that approach.

2.0 LIFE-CYCLE COST ESTIMATION

2.1 Framework for Life-Cycle Cost Estimates

The primary requirement for developing cost estimates for capital asset projects is DOE O 413.3B. During the life of a project (see Figure 2-1), various cost estimates and related documents are required to support the critical decision process, the project review process, and the annual budget formulation and execution process.[2]



CD = Critical Decision
EIR = External Independent Review
PARS = Project Assessment and Reporting System
PB = Performance Baseline
PED = Project Engineering and Design
TPC = Total Project Cost

Figure 2-1
Typical DOE Acquisition Management System for Line Item Capital Asset Projects

As one would expect, the methodology to estimate projects at CD-0 are necessarily different from that at CD-2 when design detail and specific scope has been defined. DOE O 413.3B requires that a cost estimate, or cost range, shall be provided at each Critical Decision, but the degree of rigor and detail for a cost estimate should be carefully defined, depending on the degree of confidence in project scale and scope that is reasonable to expect at that stage of project development. The following cost estimates are required at each Critical Decision (see Figure 2-2):

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[2] U.S. Department of Energy, *Cost Estimating Guide*, DOE G 413.3-21, May 9, 2011.

- CD-0, approve mission need, requires that a rough order of magnitude (ROM) cost estimate range be developed that is used to determine the acquisition executive (AE) authority and does not represent the performance baseline (PB).
- CD-1, approve alternative selection and cost range, requires that a cost estimate range be provided for the cost effective preferred solution that will meet the mission need. The recommended alternative should provide the essential functions and capabilities at an optimum life-cycle cost that is consistent with required cost, scope, schedule, performance, and risk. Therefore, LCCA are required for the alternatives under consideration to ensure that the preferred alternative provides the essential functions and capabilities at an optimum life-cycle cost. **It is the development of the LCCEs and the conduct of the necessary LCCA, which support the selection of a preferred alternative that is a primary subject of the guidance found in this handbook.**
- CD-2, approve performance baseline, establishes the performance baseline for the project and provides reasonable assurance that the design will be implementable within the approved performance baseline. The risk-adjusted cost estimate (based on identified and assessed risks and uncertainties) approved at CD-2 is used to support the project's approved PB, which includes the total project cost (TPC), scheduled CD-4 date (approve start of operations or project completion), scope and minimum Key Performance Parameters (KPPs) that must be achieved at CD-4. **At this stage of a project, LCCEs should be further developed and/or updated since they should be used to support value-engineering efforts/analyses to ensure the most effective use of project resources and lowest life-cycle costs for the final project, and are required to support future budget planning efforts.**
- CD-3, approve start of construction/execution, is a continuation of the project execution phase. The risk-adjusted cost estimate should be updated to reflect final design, project execution approaches, acquisition strategies, and planned start-up and testing requirements that have been more fully defined since the CD-2 TPC was established. **Even at this stage of a project, LCCEs need to be updated as they continue to be needed to support effective value engineering efforts and project-execution strategy decisions, in addition to supporting future budget planning during the operations and maintenance phase of the project.**
- CD-4, approve start of operations or project completion, is the achievement of project completion criteria defined in the project execution plan. The estimate at completion (EAC) should be updated and compiled for inclusion with the project closeout report.[3] **At this point, LCCEs are no longer a project concern, but the need for LCCEs and LCCAs will continue as a program need to support operations and maintenance and final disposition phases of the capital asset as well as provide support and a basis for future years' budget planning.**

[3] U.S. Department of Energy, *Cost Estimating Guide*, DOE G 413.3-21, May 9, 2011.

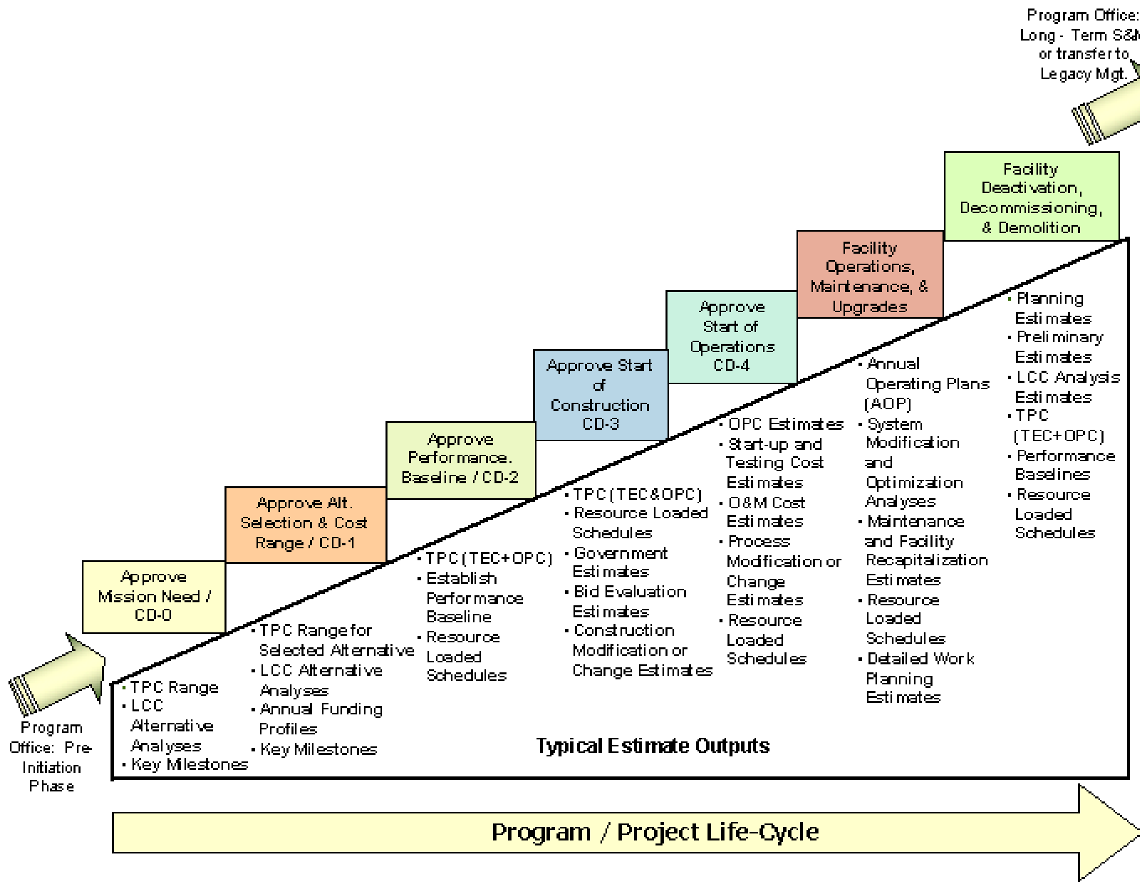

Figure 2-2
Typical Life-Cycle Baseline Estimate Ouputs[4]

GAO has noted, "Underestimating full life-cycle costs creates the risk that a program may be underfunded and subject to major cost overruns. It may be reduced in scope, or additional funding may have to be appropriated to meet objectives. Overestimating life-cycle costs creates the risk that a program will be thought unaffordable and it could go unfunded."[5]

2.2 LCCE Classifications and Methodologies

The nature and scope of the LCCE is a direct result of the definition of the project/program at the time the estimate is prepared. DOE has elected to use the widely accepted cost estimate classifications found in the AACEI's, Recommended Practice (RP) Nos. 17R-97 and 18R-97. The five suggested cost estimate classifications are listed in Table 2-1 along with their primary characteristics.

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[4] U.S. Department of Energy, *Cost Estimating Guide*, DOE G 413.3-21, May 9, 2011.
[5] Government Accountability Office, *GAO Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs*, GAO-09-35P, May 2009.

Table 2-1
Generic Cost Estimate Classifications and Primary Characteristics

Cost Estimate Classification	Primary Characteristics	
	Level of Definition (% of Complete Definition)	**Cost Estimating Description (Techniques)**
Class 5, Concept Screening	0% to 2%	Stochastic, most parametric, judgment (parametric, specific analogy, expert opinion, trend analysis)
Class 4, Study or Feasibility	1% to 15%	Various, more parametric (parametric, specific analogy, expert opinion, trend analysis)
Class 3, Preliminary, Budget Authorization	10% to 40%	Various, including combinations (detailed, unit cost, or activity-based; parametric; specific analogy; expert opinion; trend analysis)
Class 2, Control or Bid	30% to 70%	Various, more definitive (detailed, unit cost, or activity-based; expert opinion; learning curve)
Class 1, Check Estimate or Bid[a]	50% to 100%	Deterministic, most definitive (detailed, unit cost, or activity-based; expert opinion; learning curve)

It is unlikely that it will ever be necessary, or even possible, to develop an LCCE that is considered to be a Class 1 or even a Class 2 estimate in its entirety.

For the typical life-cycle cost estimate, the various elements of that estimate (see Section 2.4 of this handbook) will be estimated at various classification levels, depending on the stage of the project. For example, even at CD-2 when the capital cost of a project will be estimated at a Class 2 level, the operations and maintenance and final disposition phases of the project will most likely be Class 5 or, at best, Class 4 estimates. In all cases, those distinctions and descriptions should be clearly documented and communicated to those who will be receiving and eventually using those estimates to support management decisions, alternative selections, and budget planning efforts.

There are various estimating methodologies that apply to the estimating classes. A project cost estimate may comprise separate estimates of differing classifications. Certain portions of the design or work scope may be well defined and warrant more detailed cost estimating techniques and approaches, while other areas may be relatively immature and appropriately estimated using parametric or other less definitive techniques. Figure 2-3 shows the relationship between the estimate classification and the applicable methodologies.

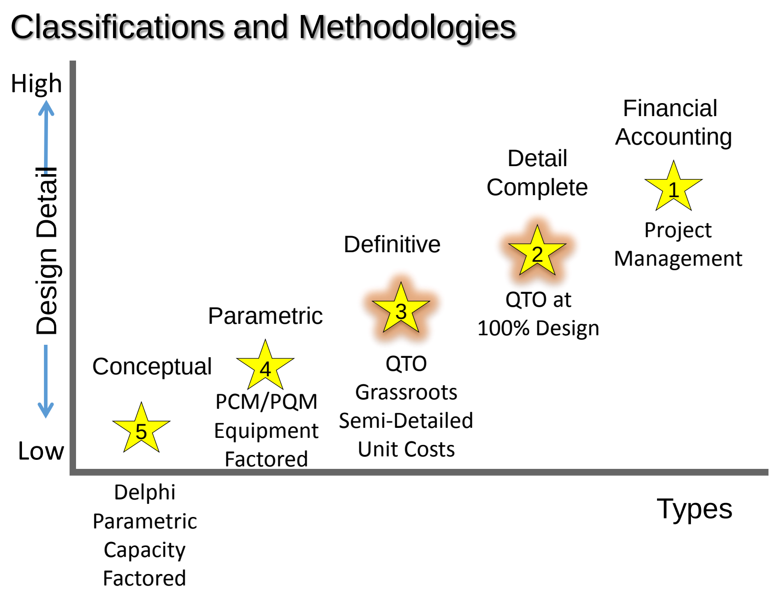

Figure 2-3
Range of Cost Estimating/Modeling Methodologies

> *Tip: The DOE Cost Estimating Guide (DOE G 413.3-21) describes the various cost-estimating techniques and approaches that can be used to develop the various classes of cost estimates.*

It should be noted that, as one moves from one estimating method to another as the project or program matures, the resources to conduct these estimates should be considered. The benefit of a detailed definitive estimate is a much improved, higher quality, defensible estimate that tightens the expected range and reduces the contingency requirements. The price for these improvements is, of course, the time and resources it takes to develop them. Figure 2-4 shows this relationship.

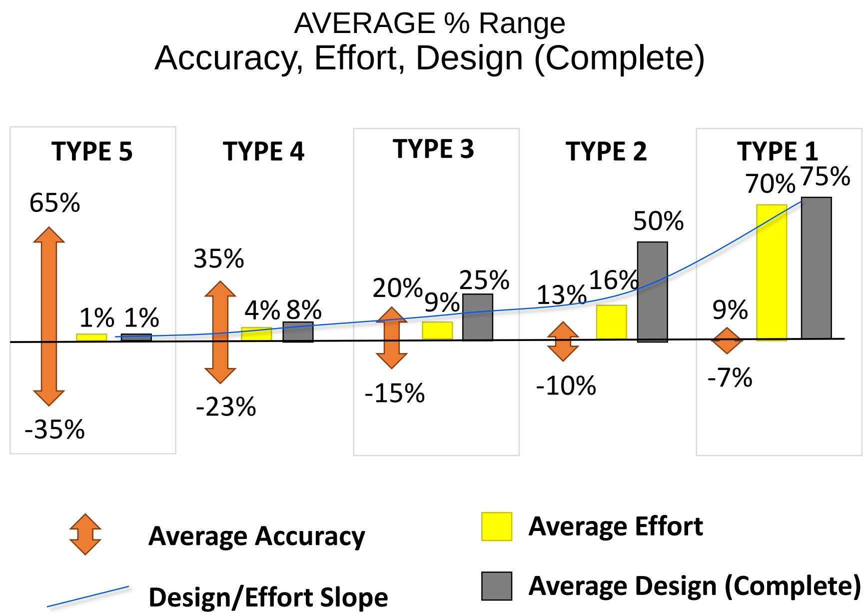

Figure 2-4: Relationship between Accuracy and Effort and Design Completion

2.3 LCCE Process

The objective for all estimates, including the LCCEs that are addressed in this handbook, is that those estimates be of high quality. GAO expects that high-quality estimates satisfy four characteristics, as established by industry best practices[6]. Thus LCCEs should be

- CREDIBLE, when the assumptions and estimates are realistic, the estimate has been cross-checked and reconciled with independent cost estimates, the level of confidence associated with the point estimate[7] has been identified, and a sensitivity analysis (i.e., an examination of the effect of changing one variable relative to the cost estimate while all other variables are held constant in order to identify which variable most affects the cost estimate) has been conducted;
- WELL-DOCUMENTED, when supporting documentation includes a narrative explaining the process, sources, and methods used to create the estimate and identifies the underlying data and assumptions used to develop the estimate;
- ACCURATE, when actual costs deviate little from the assessment of costs likely to be incurred; and
- COMPREHENSIVE, when the estimate accounts for all possible costs associated with a project or program, is structured in sufficient detail to ensure that costs are neither omitted nor duplicated, and has been formulated by an estimating team with composition commensurate with the assignment.

[6] Government Accountability Office, *GAO Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs*, GAO-09-35P, May 2009.
[7] A point estimate is the best guess or most likely value for the cost estimate, given the underlying data. The level of confidence for the point estimate is the probability that the point estimate will actually be met.

GAO has identified and defined a 12-step process that is essential for producing high-quality cost estimates. As pertains to the development of LCCEs, in particular, those steps are described and discussed below.

2.3.1 Define the Estimate's Purpose

When developing an LCCE, it is important to fully understand the purpose of the estimate and know for what objectives the estimate will be used. If the estimate is intended to support a comparison of alternatives using LCCA (as described in Section 3.0 of this handbook), it is important to maintain consistency among alternatives relative to what is included in the estimate and to assure that all areas of variability between alternatives have been addressed. Conversely, if the purpose of the LCCE is to communicate the full expected cost or liability to be incurred by a project or program, then it is essential that the costs for all phases (as described in Section 1.0) be included in the estimate, including sunk costs (those costs incurred during earlier phases of the project or program).

2.3.2 Develop an Estimating Plan

The DOE *Cost Estimating Guide* (DOE G 413.3-21) clearly describes the process and steps that are appropriate for planning how any estimate, including an LCCE, should be accomplished. It is highly recommended that no LCCE development efforts proceed until a suitable plan has been established, clearly communicated, and received concurrence from all involved parties, including eventual users and reviewers of the finished LCCE. Development of the estimate plan does not have to be extensive, and the plan can be as simple as a one-page memorandum. The objective is to ensure that all parties agree on how the estimate will be developed and used.

2.3.3 Define the Project (or Program) Characteristics

An essential step in the development of any cost estimate is to clearly define, document, and understand the characteristics of the project or program for which the estimate is being developed[8]. This is especially important for LCCE development because those characteristics drive the scope of the effort to be estimated (such as project/program phases, inclusions, exclusions, as further discussed in the next two steps of the LCCE process).

This can be done by identifying the technical and program/project parameters that will bind the cost estimate based on, among other things, the following information:

- Purpose of the project or program
- System and performance characteristics
- Any technology implications or developments needed
- System configurations
- Acquisition strategies and schedules (all phases)
- Relationship to other, existing systems

[8] These elements are typically documented in a formal statement of work, which is developed in accordance with the process and guidance presented in the DOE "Handbook for Statement of Work and Key Performance Parameters for Capital Acquisition Projects."

- Support (manpower, training, etc.) and security needs
- Recognition of areas of risk and uncertainty, including identified risk events
- System quantities for development, test, and production
- Production rates and schedules
- Deployment and maintenance plans
- Spare parts requirements and inventories
- Expected equipment and facility life
- Predecessor or similar legacy systems
- Expectations and/or requirements for final disposition.

2.3.4 Determine the Estimating Structure

A work breakdown structure (WBS) represents the best practice for structuring any cost estimate, including an LCCE. A WBS is the cornerstone of every program and project because it defines in detail the work necessary to accomplish the objectives of the program or project[9]. The WBS process provides

- A complete decomposition of the project/program into the discreet products and activities needed to accomplish the desired project/program scope (the WBS dictionary should contain in a narrative format what each activity includes);
- Compatibility with how the work will be done and how costs and schedules will be managed;
- The visibility to all important project/program elements, especially those areas of higher risk, or which warrant additional attention during execution;
- The mapping of requirements, plans, tests, and deliverables;
- A clear ownership by managers and task leaders;
- Organization of data for performance measurement and historical databases;
- Information that is the basic building block for the planning of all authorized work;
- A mechanism to track and report progress; and
- A means to ensure all elements are captured and redundancy is avoided.

GAO identifies the development and use of a product-oriented WBS as a best practice[10]. DOE concurs with this as the optimal approach and recommends that programs and projects deconstruct a project or program product into successive levels with smaller specific elements, until the work is subdivided to a level suitable for management control.

However, for the purposes of evaluating a project or program life cycle and to provide a structure for development of LCCEs that are assured to be all-inclusive (or at least appropriately inclusive, depending on estimate purpose and use), it is more appropriate for the first level of the WBS to focus on life-cycle phases, rather than specific products or subproducts. The more product-oriented approach can then be taken to further sub-divide and fully understand the elements, requirements, activities, deliverables, etc. to be accomplished (and therefore estimated) for each phase of the program or project life cycle.

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[9] The WBS for a project should be linked to the statement of work, in accordance with the guidance provided in the DOE "Handbook for Statement of Work and Key Performance Parameters for Capital Acquisition Projects."

[10] Government Accountability Office, *GAO Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs*, GAO-09-35P, May 2009.

To the extent practicable and appropriate, programs are encouraged to develop and direct the use of a standard WBS and WBS development approach for all program elements and projects. In this way, consistency can be achieved and comparisons among programs and projects can be facilitated.

In order to assist the DOE community with the development and evaluation of WBSs for LCCE purposes (as well as program/project management and control), Appendix B of this handbook presents a suggested WBS. This LCC WBS is an example and guidance tool that is not required to be used as is. Depending on the nature and requirements of the projects or programs, the suggested structure may contain more levels than needed, areas that are not relevant, and elements that need to be broken down to an even lower level of detail, and may be missing elements that need to be added.

> *Tip: The suggested LCC WBS included as Appendix B can be used as a checklist to ensure all relevant cost elements are captured for LCCE purposes.*

2.3.5 Identify Ground Rules and Assumptions

As specified in the DOE *Cost Estimating Guide*, it is essential to define, and clearly communicate, the ground rules and assumptions that comprise the basis for any cost estimate. This step is especially important for LCCEs that are, by definition, built on many assumptions regarding variables and future-year needs and expectations. Some pertinent assumptions to be considered when developing a LCCE include

- the estimate's base year including its time phasing and life cycle;
- project schedule information by phase;
- project acquisition strategy;
- any schedule or budget constraints and funding assumptions;
- inflation assumptions;
- use of existing facilities or new modification / development;
- technology refresh cycles;
- technology assumptions and new technology to be developed;
- commonality with legacy systems and assumed heritage savings;
- effects of new ways of doing business;
- production rates and learning curves; and
- end-state conditions (existing at conclusion of operations and needed to achieve).

> **For an LCCE, it is especially important to clearly define the LCC boundaries, not just with respect to the specific estimate being developed, but also its association to other affected projects or programs.**

In addition to clearly identifying critical and specific inclusions, exclusions, and assumptions, the LCCE basis should define the entire scope of the LCCE and delineate what is or is not included in the LCCE. For projects, this scope should be based on the mission need as described and approved at CD-0. But variations may be appropriate given the nature and purposes of the estimate being developed, as previously discussed. Example 2-1 illustrates some of these boundary assumptions for a hypothetical LCCE.

Example 2-1
Boundary Assumptions

A program calls for shipment of a quantity of waste to a receiving facility. The LCC may address, for example,

Inclusion: The waste handling and packaging costs are included in this LCCE.

Exclusion: The transportation and disposal cost are not included, as those costs are already captured in a different program's LCC.

Assumptions:

- The waste receiving facility is prepared to accept this quantity during this period.
- The new waste management facility will be deactivated and decommissioned as part of the LCCE. Alternatively, it may be assumed that there is useful life remaining that another program/project can acquire.
- The site of this operation will be turned back to the public domain (the state) and will require that legacy waste and any environmental restoration be conducted.
- A stipulated portion of the site work (e.g., running electrical service to the site, access road construction) will be covered by the landlord or another program.

The LCCE development process is when decisions can be made and documented about the scope of a project or program. Every ongoing project that is influenced by the implementation or operation of the project/program should be addressed, negotiations made, and agreements reached during this process.

It is important to draw a "box" around the scope for the subject LCCE and to clearly document that definition. For instance, the mission need at CD–0 might state that all transuranic waste at the site must be dispositioned to satisfy the short-term and long-term health and safety requirements as set forth by the stakeholders in binding legal agreements (a consent order). It is this mission need that will dictate scope for the LCCE and LCCA. So, the scope of an acquisition project for a waste management facility may include the facility design, construction, facility operations and maintenance, and final disposition, but not process operations that provide the feed to that facility. At CD–2, the performance baseline for this project may stay within this box. An LCCE (and associated LCCA) that needs to support alternative selections at CD-1, on the other hand, may require that the LCCE scope box be extended to include these process operations in order to allow comparison of this alternative to another alternative, where the waste is left in place and maintained with an engineered cover.

2.3.6 Obtain Data

In addition to the guidance to be found in the *Cost Estimating Guide*, Sections 2.4 and 2.5 of this handbook provides further guidance on approaches and data sources that can facilitate the development of LCCEs.

2.3.7 Develop a Point Estimate and Compare to an Independent Estimate

The processes, techniques, and methodologies to be used to develop a LCCE are generally the same as those used for more traditional project cost estimates, as described in the *DOE Cost Estimating Guide.* It should be noted, however, that the use of, and comparison to, independent cost estimates is equally important for LCCEs as it is for those more traditional cost estimates. The rigor and requirements for such independent cost estimate efforts should be consistent with the purpose and intended use of the LCCE.

2.3.8 Conduct Sensitivity Analysis

In some respects, sensitivity analyses, as described later in Section 4.4 of this handbook, are even more important for LCCEs and LCCs than they are for more traditional cost estimates. This is because the nature of the assumptions and variables involved are likely much more diverse and potentially will significantly influence the resulting LCCE values and, more important, the outcome of an LCCA (regarding the most economically beneficial alternative).

2.3.9 Conduct Risk and Uncertainty Analysis

This step is fully discussed and described in Section 4.3 of this handbook.

2.3.10 Document the Estimate

The guidance to be found in Section 6.7 of the DOE *Cost Estimating Guide* is equally appropriate for documenting LCCEs. As pointed out in that document, well-documented LCCEs are essential for several reasons:

- Complete and detailed documentation is essential for validating and defending LCCEs.
- Documenting the LCCE in detail, step-by-step, provides the documentation that will enable someone unfamiliar with the program or project to easily recreate or update the LCCE.
- Good documentation helps with analyzing changes in program or project costs and supports the collection of the cost and technical data that can be used to support development of LCCEs in the future.

This topic is covered to some extent also in Section 5.2 of this handbook.

2.3.11 Present the Estimate for Management Approval

Because LCCEs and LCCAs built from those LCCEs are intended to support management decisions, those estimates and analyses need to be appropriately reviewed, vetted, and approved. The presentation of the estimate needs to clearly describe the approaches used to develop the estimate, the assumptions, and boundaries that form the basis for the estimate, and summarize and clearly present the estimate results in a manner that fully informs those management decision makers and other stakeholders who are the ultimate user or consumer of the estimates. (See Section 5.1 for more guidance on this step.)

2.3.12 Update the Estimate to Reflect Actual Costs and Changes

There are many considerations to make and maintain during the LCCE process. The LCCE is a living document. As the project commences, an initial LCCE will be developed using the conceptual estimating methods described in the DOE *Cost Estimating Guide*. The LCCE should be maintained as the project matures, and the conceptual estimates replaced with definitive estimates (e.g., project performance baseline). The updated LCCE is used to determine future budget needs, manage changes in project scope and technical approach, and prioritize work activities. It is important to keep a running tally of the inclusions, exclusions, and assumptions for each LCCE that is developed over the life of a project or program.

Upon completion of a life-cycle phase, the data should be entered into a historical database.[11] The actual costs can be compared to the original baseline or estimate and any cost growth identified and analyzed; therefore, cost risk can be evaluated for future projects with similar challenges. Evaluating changes to inclusions, exclusions, and assumptions provides a means to understand how and why the project/program experienced this cost growth. Such data can be used for many purposes, including cost model validation.

2.4 Estimating LCCE Elements

2.4.1 Project Costs (Phases 1-4)

The costs of capital asset projects, or comparable program elements, should be estimated using the methodologies and guidance presented in the DOE *Cost Estimating Guide*. That guidance should be appropriate to cover all elements in Phases 1 to 4 as discussed in Section 1.0 of this handbook and as shown in the sample WBS included as Appendix B.

Appendix C.1 provides an example of the estimate for Phases 1 to 4 of a hypothetical radiological laboratory. That example will also be used for illustrating the guidance and concepts discussed in the following sections for developing the LCCE for Phases 5 (Section 2.4.2) and Phases 6 and 7 (Section 2.4.3).

A separate example of the LCC for an ER project is included as Appendix C.4.

2.4.2 Operations and Maintenance Costs (Phase 5)

Operations and maintenance (O&M) costs should be estimated with the same rigor and quality as are the capital project costs that are more traditionally understood. The elements to be captured in these estimates include those shown under WBS 1.5 in Appendix B.

[11] Projects should maintain historical data/records, and programs should keep track of the historical costs (estimates and actual costs) for their projects to provide a basis and source for the development of future LCCEs. These efforts should be coordinated as well with DOE's Office of Acquisition and Project Management.

For early estimates of LCCs, it may be appropriate to estimate such costs at a summary level using analogies or other parametric approaches and appropriate historical actual cost data for comparable projects or facilities. For example, the annual O&M costs can be determined by scaling the costs of another similar facility based on an appropriate metric. Examples may include building area or volume, production throughput or capacity, or another appropriate benchmark or metric value. See Example 2-2 for an illustration of this approach.

Example 2-2
Parametric O&M Estimate

The table below shows the basis for and resulting estimate developed, for annual O&M costs for a hypothetical new laboratory facility at a DOE site. Valid historical data for a comparable facility (or average from multiple comparable facilities) is available that can be used to develop a Class 5 estimate for this new facility.

Note: Data presented in this example is fictitous, very simplistic, and does not represent any real historical DOE data			
Existing Data - similar DOE laboratory facility			
Annual Facility O&M		6,500,000	
Facility Size		30,000	sf
Annual Laboratory O&M		10,000,000	
Number of Samples Tested		2500	
Total Annual Costs - Existing Facility		16,500,000	
Estimate of Annual O&M for New Facility			
Size of New Facility		46,000	sf
Expected No. of Samples/Year		3300	
Annual Facility O&M Costs		9,150,000	
Used .8 exponent scaling factor			
Annual Cost of Testing Operations		13,200,000	
Assumed same unit rate as other			
Total Estimated Annual O&M Costs		**22,350,000**	

As a project matures, much more detailed estimates of the O&M costs will be required to support future budget planning and requests and further the understanding of variations and sensitivities in O&M costs as variations in conditions and scenarios occur. Estimates should then be developed that address the primary components of O&M, using appropriate data sources and estimating tools, as described below and in Section 2.5. It is usually a good practice to estimate

O&M costs using an activity-based cost (ABC)[12] approach and in terms of annual costs. However, any periodic variations (additions or deletions) from typical annual estimates also need to be identified and captured in the LCCE.

O&M estimate considerations are discussed in the following paragraphs.

- **Fixed versus variable costs.** A very important consideration when estimating O&M costs for projects, and in particular when evaluating such costs to support LCCAs that will compare various alternatives, is to fully understand the concept of fixed and variable costs. Fixed costs are those costs or elements that will not change, no matter the production level or capacity being considered. Conversely, variable costs are those that will vary in proportion to varying levels of capacity or production.

  For example, the management staff of a production facility is fixed, but the actual operating staff may vary as production levels change, work shifts are added or eliminated to match production needs, etc. It may be necessary to look even further into such a situation. A core operating staff may actually represent a fixed cost since it is essential to retain key expertise and a cadre of experienced personnel. The variable component may represent more of surge capacity as staff is added or deducted to better match capacity or production needs.

  > **LCCEs and, especially, LCCAs need to carefully review and consider the assumptions of the scenarios being evaluated and develop estimates, and variations between estimates, that appropriately reflect the differences between fixed and variable costs.**

- **Indirect versus direct costs and site overhead/cost allocations.** Although an ABC approach typically requires that indirect costs be appropriately allocated to direct cost elements, that practice is not an essential requirement for LCCEs[13]. Rather, it is important to ensure that all costs are captured, regardless of whether they are or will be categorized and treated as direct or indirect costs.

  > **It is important to understand the processes and practices in place at a site for allocation of indirect or overhead cost elements when considering a project, or a set of project alternatives, that will be deployed within an existing site.**

  Many DOE sites have established cost allocation models that distribute costs differently depending on the nature of the activity—capital projects may receive one overhead adder, site staff functions another, and production operations or other ongoing activities yet another adder. Thus, the typical LCCE that is composed of various elements may need to incorporate various adders specific to the type of element involved. Even more importantly, alternatives that will compare very different approaches, such as construction of a new facility or project

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[12] Refer to the DOE *Cost Estimating Guide* for more information on activity-based costing.
[13] For example, the elements that comprise general and administrative costs for a site or facility, like general management, human resources, etc., are considered indirect costs that are spread or allocated across the direct work elements, like production operations, using a preset formula or relationship.

versus modification or upgrade of existing facilities, may have vastly different overhead allocations that should be considered and included in the LCCEs.

- **Labor (staff) costs.** Annual O&M costs for most DOE projects and programs are dominated by labor costs. Those labor costs represent the cost of all levels of staff, from upper management through shift operations to maintenance, housekeeping, clerical support, etc. Labor costs include the salaries and wages that are paid to the workers and all payroll burdens for taxes and fringe benefits, via an appropriate allocation/calculation methodology.

  Within DOE, the costs of Government employees (i.e., DOE employees) are generally not captured in either project or program cost estimates. Rather, the costs to be considered are those incurred by contractors, consultants, and other non-DOE employees who work on or support the project or program. However, when using LCCAs to compare alternatives that may involve variations in DOE staff levels (most likely for a program-level analysis), it would be best to also include DOE staff costs in the analysis to ensure the true relative costs of each competing alternative are recognized and understood.

  Because labor/staff costs are such an important element within the O&M portion of an LCCE, the basis for such estimates should be very clearly defined, understood, and documented. That basis should be supported by the identification of
    - organization charts;
    - staffing models;
    - comparisons to other facilities/projects;
    - assumed work hours per shift;
    - assumed number of shifts per day/week/month/year;
    - assumed portion of direct productive work time out of total available time; and
    - basis for salary structure/rates and burdens/benefits rates.

  To the extent possible, staff/labor costs should be tied to activities to be accomplished, rather than viewed only from a level-of-effort perspective. Some of those activities are discussed below (maintenance, site programs). Ongoing production or programmatic operations should be based on assumed production rates, facility capacity factors, throughput requirements, or other appropriate parameters whenever possible and to the maximum extent practical.

- **Utility costs/charges.** Although not always a key cost driver within the context of a total project or program LCCE[14], the costs for utilities such as electricity, gas, steam, water can be a key driver for the comparison of alternatives within an LCCA. Variations in the utility requirements and consumption rates of various alternatives, as well as sources of those utilities (e.g., self-generated versus commercially purchased) need to be carefully evaluated and estimated. This may be especially true when considering energy efficiency–related alternatives.

[14] There are, however, cases where utility charges are a significant cost driver, such as certain Office of Science projects.

Whatever the case, as with all other LCCE elements, the basis and assumptions for the estimated values should be clearly defined and documented. To the maximum extent possible, the sources of rates and other cost data should be clearly explained and communicated and should come either from other comparable projects or from appropriate and widely available industry reference sources.[15]

- **Maintenance costs.** Maintenance costs are one area of staffing for which it should be possible to develop a sound, historical-data-based, cost estimate. Maintenance is composed of two major types: preventive and corrective.

  The level and extent of preventive maintenance is based on established requirements and procedures developed for a facility or operation. Accordingly, those procedures and requirements can form the basis for estimating the number of staff required to accomplish preventive maintenance in a typical year.

  Corrective maintenance estimates should ideally be based on valid historical data for comparable projects, facilities, processes, etc., that delineate expected or assumed failure rates and extent of maintenance needed to address and correct those situations.

  Tip: A portion of corrective maintenance may be a variable cost, as the cost of corrective maintenance may change as capacity or production levels vary.

- **Materials and supplies.** The costs of materials and supplies (M&S) is typically estimated using some parametric relationship (such as the percent of staff costs), especially for early LCCEs when O&M definition is immature. In such cases, the basis and source used to derive those parameters should be appropriately comparable to the project/program being estimated and should be clearly documented.

  As more knowledge is gained, however, it should be possible to develop more definitive M&S estimates using vendor price sheets, commercial data bases, etc., and applying appropriate rates to estimated quantities to be required. Care should be taken when developing M&S estimates to consider both fixed (e.g., office supplies) and variable (e.g., consumables for production processes) elements in an appropriate manner.

- **Site support, security, management programs.** When considering the LCCE for a project or program to be situated at an existing DOE site, the LCCE should consider and include any additional costs that will be borne due to added requirements or costs to be incurred at the site. Those may relate to security (staff, systems), management programs (e.g., quality assurance, environmental safety and health, and safety), infrastructure support, or other elements, as appropriate. Those requirements or costs need to be looked at for each alternative being evaluated and estimated.

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[15] For example electric rates (cost per kWh, can be found through the EIA at http://www.eia.gov/totalenergy/data/monthly/pdf/sec9_11.pdf

Conversely, a project or program that will be situated at a grassroots site, or that will be expected to operate autonomously from an existing site, will need to include all general site costs as appropriate in the LCCE and LCCA.

- **Spare parts, upgrades/replacements, and periodic major upgrades.** Another important element to be captured in an LCCE, and for which various alternatives may have disparate assumptions and resulting estimates, involves the ongoing needs for spare parts, routine upgrades or replacements of equipment and hardware, and potential periodic major upgrades or refurbishments. All of these elements must be clearly defined, the assumed requirements clearly specified, and appropriately high-quality cost estimates developed in accordance with the guidance in the DOE *Cost Estimating Guide*. It is especially important to document the assumptions made as to the frequency and timing of these requirements to facilitate a reasonable LCCA.

Example 2-3 presents a more detailed O&M cost estimate to illustrate the guidance presented above.

Example 2-3
Detailed O&M Estimate

Appendix C.2 presents a detailed cost estimate of annual O&M costs for the hypothetical laboratory example previously presented in Section 2.4.1 using the WBS provided in Appendix B. While this level of data may be considered to represent a Class 4 estimate, even more detailed and bottom-up estimates may be possible and required as a project becomes more mature and the operations phase becomes better defined and understood.

As can be seen, the total cost derived in Appendix C.2, $22,600,000 compares closely with the parametrically developed estimate shown as Example 2-2.

Note that the data presented in both of these examples is hypothetical and represents fictional data provided for guidance illustration only.

2.4.3 S&M / Final Disposition Costs (Phases 6-7)

The final steps in the project or program's life cycle are often neglected in its early phases. Even a life-cycle baseline developed by the cognizant program office may consider only a portion of this phase, by assuming the property owner, rather than the program, will be responsible for this activity or that for some reason the liability will not be in their purview.

The LCCE and associated LCCA should consider this last phase in its entirety. If the liability goes beyond the foreseeable future, it may be better considered in qualitative terms. Most projects and programs, however, have a quantifiable conclusion.

This phase, like other LCC phases, can be estimated using a variety of methodologies, and the DOE *Cost Estimating Guide*, should be relied on for more in-depth guidance on possible techniques/approaches that may be appropriate.

> **One of the best methods for estimating S&M and final disposition costs is to understand and use historical costs for similar activities.**

The EM Environmental Cost Analysis System (ECAS) was created to provide the DOE community with a historical cost database. It currently has 124 completed decontamination and decommissioning (D&D) projects from throughout the DOE complex.[16]

Cost analysts have used ECAS data to derive building types that share characteristics with respect to the scope of their final disposition within categories such as the following:

- Accelerator
- Hot cells
- Maintenance and industrial
- Major radiological laboratories
- Manufacturing
- Minor radiological laboratories
- Nonradiological manufacturing
- Office
- Plutonium special nuclear material facility
- Reactor
- Tritium special nuclear material facility
- Uranium special nuclear material facility
- Warehouse
- Waste processing
- Waste storage.

This classification is useful to help find an analogous project that can be used to derive at least a Class 5 estimate. Similar projects, if identified, can also be used to establish default scope for a project.

An additional DOE tool is the Active Facilities Data Collection System (AFDCS) cost-estimating tool. This tool is a key element in the process by which the DOE's Office of Finance and Accounting (OFA) develops estimates of the life-cycle environmental liability costs associated with DOE's active facilities; that is, those not formally part of the current EM inventory of surplus facilities for final disposition. A recently completed study commissioned by OFA verified and validated the AFDCS[17]. Because of this validation, the AFDCS model will be updated in future years.

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[16] This database is not in the public domain; access is controlled by DOE's EMCBC.
[17] DLE Technical Services, LLC, and Team Analysis, Inc., *Final Validation Report on Active Facilities Data Collection System Cost Models for the DOE Office of Finance and Accounting*, September 16, 2014

In addition to the ECAS historical database and the AFDCS model within DOE, there are parametric tools available for estimating D&D costs[18]. However, in general, these tools sometimes do not include the first scope elements for stabilization or S&M. Whatever tool, model, or historical data is chosen to assist with the development of estimated costs for Phases 6 and 7 of a project life cycle, care must be exercised to ensure the full scope of required activities and durations is captured, and the approaches and techniques used to accomplish the final dispositioning is appropriate and reasonable.

The activities or sub-phases that are included in Phases 6 and 7 are described below.

- **Facility shutdown or deactivation** represents the official DOE approval processes to end operations and move into a shutdown state, eventually leading to final disposition of the facility. The deactivation activities needed to achieve this state may also consist of activities to prepare for decommissioning that are of a more operational nature, such as draining of tanks, removal and repackaging of packaged waste generated during operations, isolation of the building from site utilities. These activities are often more efficiently performed by operational staff using operational procedures. This sub-phase typically does not involve size reduction and removal of equipment, or similar activities.

- **Stabilization** consists of those active efforts to stabilize, remove, and (if necessary) safely store materials (e.g., special nuclear materials and spent nuclear fuel) that represent material at risk (MAR) and require maintenance of nuclear facility status. It also includes general activities necessary to allow a facility to be placed in a lower cost status or major efforts to maintain building containment (e.g., sealing surface contamination, grouting drains to prevent contamination spread, and re-roofing a building to avoid roof collapse) for some period before decommissioning. It does not include reactor entombment (such as preparation for decades of component radioactive decay).

- **Surveillance and maintenance** consists of the ongoing activities to maintain the safety and security of the facility and materials contained in that facility until final dispositioning can be accomplished. Examples of S&M activities include preventive maintenance, corrective maintenance (as necessary to maintain facility function, not operational function), control points (when necessary), safety access controls, periodic surveys, and similar activities. It does not include active efforts to reduce costs or prepare for decommissioning.

- **Final disposition** may include some combination of stabilizing, preparing for reuse, deactivating, decommissioning, decontaminating, dismantling, demolishing, and/or disposing of real property assets. The full scope and requirements for final disposition can vary widely depending on the nature of a facility, the characteristics of a site, and the regulatory framework and requirements that govern the activities. This phase typically begins with a planning and scoping effort, followed by some detailed engineering to determine work

[18] Some DOE sites have developed their own D&D estimating models/approaches. Idaho National Engineering Laboratory (INEEL) in particular has developed a fairly rigorous process model, and Savannah River Site (SRS) has adapted and used that model for its D&D estimates. Those models are not included in this handbook at this time since the currency of the data and validity of the models has not been verified.

approaches and define work packages suitable for the contracting and execution strategy selected.

Tip: When estimating final disposition costs, be sure to select a scenario and approach that is reasonable given the nature of the facility, the characteristics of the site, and the regulatory requirements that will likely be in place.

Example 2-4
Estimate of Phases 6 and 7 for Radiological Laboratory Facility

Appendix C.3 presents the results of a parametric estimate of the costs for Phase 6, long-term S&M (Table C.3-1), and Phase 7, final disposition (Table C.3-2), for the hypothetical radiological laboratory facility previously discussed in Sections 2.4.1 and 2.4.2. The estimate was developed using a combination of the Remedial Action Cost Engineering and Requirements System (RACER) and the Parametric Cost Engineering System (PACES) parametric models (See Section 2.5 for descriptions of these tools).

Although the Phase 6 S&M cost is an order of magnitude less than the Phase 7 D&D, it is not trivial. This example shows the concept of the scope and estimating considerations for these phases. However, specific site conditions will likely have significant positive or negative effects on the estimated costs. Sites that have waste management facilities onsite for disposal of low-level waste or mixed waste will experience lower disposal costs. A campaign approach to perform D&D on a number of collocated facilities at once will benefit from the economies of scale and avoid repeating regulatory compliance activities, among other things. Reducing the S&M timespan, not mothballing facilities for years while awaiting funding or decision-making would similarly reduce the S&M costs.

2.5 LCCE Tools

The following listing provides a classification or grouping of the appropriate tools that can be used to develop LCCEs and describes their attributes. Appendix D contains further descriptions of these tools and provides contact information that can be used to research prices, training requirements, and other related information. As can be seen, there are a wide range of tools available and users of this handbook should carefully evaluate and select the tool(s) best suited to their needs and applications.

2.5.1 Quantity-Take-Off Tools

The tools identified in this section may be used to estimate projects following the bottom-up or quantity take-off (QTO) estimating method. While there are many such tools available in the industry, the QTO tools listed in this handbook were selected because at least one Government agency requires the use of the tool. The U.S. Navy requires Success Estimator. The Army developed the Micro Computer-Aided Cost Estimating System second generation or MII, and makes it available at no cost (training is required to acquire it). The DOE Environmental Management Consolidated Business Center (EMCBC) uses MII for its detailed estimates.

1) Success Estimator: While Success provides a means to define custom logic to calculate quantities, it is primarily a detailed QTO estimating system. Both RSMeans and Cost Book/Unit Price Book (UPB) databases can be included.

2) Micro Computer-Aided Cost Estimating System (MCACES) II: MII is primarily a detailed QTO estimating system. Both RSMeans and Cost Book/Unit Price Book (UPB) databases can be included.

2.5.2 Parametric Modeling Tools

The tools identified in this section are used to estimate projects following the parametric modeling methodology. There are two primary approaches to this methodology: parametric cost modeling (PCM) and parametric quantity modeling (PQM). The PCM approach sets “cost” as the dependent variable, and the cost-driving technical parameters are the independent variables. On the other hand, PQM sets “quantity” as the dependent variable; that is, models are based on algorithms selecting and quantifying the appropriate assemblies or items from a database to build the estimate.

Both approaches are valid for developing parametric models. It is up to the end users to determine which approach, and, therefore, which tool best fits their goals. PCM is more suitable for changing historical cost data given its ease of adjusting cost curves. PQM is more suitable to using unit-cost databases and can be used to supplement QTO estimates.

Although there are likely other tools that can be used, the parametric modeling tools described in this handbook have been through the verification, validation and accreditation (VV&A) process according to Department of Defense (DoD) Instruction 5000.61, which provides some authority for their use within DOE.

3) IDEAL cost modeling platform: This parametric cost model development platform is used to develop advanced models using either the PCM or PQM approach. IDEAL facilitates both the development and deployment of cost models. As such, it allows an estimator to integrate models from multiple sources into one estimate. IDEAL is also able to fit into existing workflow and interface with existing systems via database, Excel, and XML integration. There are both desktop and on-line versions of the system sharing data in both directions.

4) ENVision cost-to-complete cleanup cost models: ENVision is used to estimate environmental remediation costs. In particular, it can estimate feasibility studies, site work, waste removal, containment, treatment, and disposal. ENVision uses the PCM approach and is developed within the IDEAL cost modeling platform.

5) Remedial Action Cost Engineering and Requirements System (RACER): As with ENVision, RACER is used to estimate environmental remediation costs. In particular, RACER can estimate feasibility studies, site work, waste removal, containment, treatment, and disposal. RACER employs the PQM approach.

6) Parametric Cost Engineering System (PACES): PACES uses the PQM approach like RACER, but its subject matter is building construction organized by a library of facility types and functional space areas. PACES uses the RSMeans database and organizes estimates by the Uniformat II WBS and tasks (line items) by the Construction Standards Institute's (CSI) MasterFormat structure. The CSI structure is a standard construction industry code of accounts.

2.5.3 Cost Databases

7) Whitestone Research: For O&M costs, a good set of industry data is published and sold by Whitestone Research and can be found at www.whitestoneresearch.com.

8) RSMeans: This complete database of costs for commercial and residential construction has over 75,000 unit prices and 25,000 building assemblies.

9) Cost Book/Unit Price Book (UPB): This database contains construction cost data for approximately 70,000 cost tasks. Cost Book is used by MII for the development of line item costs associated with the project cost estimate.

10) Environmental Cost Analysis System (ECAS): This comprehensive, web-accessible database was developed by the EMCBC, Office of Cost Estimating and Project Management Support. The database
    - contains actual cost data from 278 DOE projects;
    - includes radioactive and hazardous waste quantities;
    - has 85 discrete cost and noncost project attributes;
    - is organized by the environmental cost element structure (ECES); and
    - provides project descriptive information.

11) Facility Information Management System (FIMS): This database may be able to find appropriate costs or rates to use to develop O&M estimates. See https://fimsweb.doe.gov/FIMS/login.jsp

3.0 LIFE-CYCLE COST ANALYSIS

3.1 The Concept of LCCAs

For DOE, LCCA is the process used to determine the most cost effective option among alternatives, and to fully document the selection process. In many cases, the objective of a program is to eliminate a problem (e.g., toxic waste, inefficient machinery, unsafe conditions). In such cases, the benefit (elimination of the problem) may be considered equivalent among all alternatives, and the analysis need only consider discounted monetized cost. Other DOE programs—particularly in the Office of Science, wherein high-technology concepts with varying levels of scientific worth are commonly considered—will require full assessment of expected net value. The standard criterion for deciding whether a program can be justified on economic principles is net present value (NPV), which is the discounted monetized value of expected net benefits (i.e., benefits minus costs).

The process used to conduct LCCA comprises those tasks that enable a comparative investigation of competing project or program alternatives. The process begins with developing a life-cycle cost estimate for each alternative, generally including all costs for all project phases.

> *Tip: It may sometimes be preferable to focus only on those elements that will vary between alternatives, rather than assessing all facets of an LCC. This enables the relative merits of each alternative to be clearly distinguished without the distortion created by including large, but unchanging cost elements.*

An LCCA seeks to find the best value solution by linking each alternative to how it satisfies a strategic objective. The analysis presents facts and supporting details in addition to assessments of cost. The process is sometimes defined as a business case analysis or cost-benefit analysis, but in this handbook it will consistently be termed LCCA. An LCCA considers not only all the life-cycle costs that an LCCE identifies but also quantifiable and nonquantifiable benefits when they differ among alternatives and can be assessed. The LCCA should be unbiased by considering all practical alternatives and should not be developed solely for supporting a particular solution. Moreover, it should be rigorous enough that independent auditors can review it and clearly understand why a particular alternative was chosen.

For each alternative, the LCCA should be documented with the following information:

- Relative life-cycle costs and benefits
- Methods and rationale for quantifying the life-cycle costs and benefits, including definition of assumptions, analyzing alternatives, applying escalation, and discounting for NPV
- Effect and value of cost, schedule, and performance tradeoffs
- Sensitivity to changes in assumptions and discount rates
- Risk factors.

In addition to supporting an investment decision made in support of a Critical Decision, the LCCA should be considered a living document and updated often to reflect changes in scope, schedule, or budget. In this way, the LCCA is a valuable tool for validating decisions to sustain or enhance the enterprise through ongoing value engineering assessments.

3.2 Project Analysis

The principal technique for evaluating project alternatives is to calculate the NPV for each project alternative considered (e.g., site selection, materials of construction, development timespan) in developing a project. The project analysis compares the costs and benefits (when there is a perceived benefit difference among the alternatives) of each alternative. For example, for a given ER project the least expensive alternative may be to leave waste in place and cap it, versus treatment and shipment for disposal. The long-term costs of S&M would need to be included in this example. In another example, a method for tritium production might consider particle accelerator production, versus irradiation of lithium rods. These alternatives would entail very different concepts, types of cost, and timespans.

To avoid perceived bias, care must be taken in assigning monetary values to future benefits. This is particularly true when evaluating an alternative that produces a seemingly better result. For example, in high-technology science projects, an alternative may provide "better science" than competing alternatives' technologies. Assigning monetary values to "better" conditions can be controversial and a major determinant in the alternative selection. Thus, the measurement of relative value must be carefully done and fully documented. In every case, all the costs for the competing solutions and benefits to be derived are determined and brought to an NPV figure.

The cornerstone of NPV calculations is the selection and application of an appropriate discount rate. The discount rate is a percentage applied to expenditures expected to be made in the future (or payments received in the future) that converts the future amount to its equivalent today. Estimation of the present value of future benefits/costs is highly sensitive to the choice of a discount rate. OMB *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs* (Circular No. A-94) gives specific guidance on discount rates for evaluating federal programs whose benefits and costs are distributed over time. As described in the circular, a "real" discount rate of 7 percent should currently be used, as this rate approximates the marginal pretax rate of return on an average investment in the private sector in recent years. Changes in this rate will be reflected in future updates of the circular, and the current circular should always be used for DOE LCCAs.

Before defining the "real" discount rate, an understanding of the "nominal" interest rate is needed. The nominal interest rate is simply the stated interest rate guaranteed by an issuer. It is the actual monetary price that borrowers pay to use a lender's money. The "real" interest rate is so named because it states the "real" rate that the lender or investor receives after inflation is taken into account; that is, the interest rate that exceeds the inflation rate. If a bond that compounds annually has a 6 percent nominal yield and the inflation rate is 4 percent, then the real rate of interest is only 2 percent. In essence,

Nominal interest rate – Inflation = Real interest rate

> *Tip: When using constant year dollars, without escalation added, a real discount rate should be used to calculate NPV. When escalated, or as-spent, dollars are being used for the analysis, a nominal (or higher) discount rate should be used.*

A commanding knowledge of the project's cost-driving parameters is required to analyze the alternatives. It is important to understand what is driving the costs and the time phasing of those costs for each alternative. Developing an LCCA may greatly assist in understanding the cost drivers and thus directly influence a project's design and implementation planning.

Funding constraints are a major consideration in most DOE and National Nuclear Security Administration (NNSA) programs, and they must be assessed within the context of LCCA development. Such constraints can force schedule considerations that may make a less attractive alternative the favorable selection in terms of NPV, such as when funding constraints slow a program component schedule to the extent that out-year expenditures appear more favorable when brought to a present day basis.

NPV is computed by assigning monetary values to benefits and costs, discounting future benefits and costs using an appropriate discount rate, and subtracting the total of discounted costs from the total of discounted benefits. (As mentioned, solutions with equal benefits need consider only costs) The process transforms gains and losses occurring at different times to a common unit of measurement. A discussion of the mathematical process used to calculate NPV for two competing alternatives is provided in the Example 3-1.

Example 3-1
Comparative Life Cycle Costs

In this example, both Project A and Project B are assumed to be production facilities that provide an equally acceptable product over a 20-year useful life. Project B requires a shorter and less expensive construction span, but runs at a higher operating cost, is expected to be more expensive to disposition (i.e., develops a higher environmental liability), and has no salvage value. Project B yields an excess capacity than can generate $5 million per year revenue stream.

Capital Project A							
Element				**Estimated Cost**			
Capital Project Cost	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Total**
Project Management	6,000,000	7,000,000	8,000,000	5,000,000	2,850,000	-	28,850,000
Design	25,000,000	15,000,000	-	-	-	-	40,000,000
Procurement	5,000,000	20,000,000	5,000,000			-	30,000,000
Construction	-	15,000,000	40,000,000	85,000,000	30,000,000	-	170,000,000
Title III	-		3,000,000	3,000,000	2,500,000	-	8,500,000
Transition to Ops	-			5,000,000	35,000,000	-	40,000,000
	36,000,000	57,000,000	56,000,000	98,000,000	70,350,000	-	317,350,000
Operations and Maintenance Cost							
Annual O&M (Assume 20 years @ $50,000,000/year)						50,000,000	1,000,000,000
Periodic Capital Replacements (Assume $20,000,000 each in year 10, 15, and 20)						-	60,000,000
Final Disposition Cost							
Deactivation/Decommissioning in year 26							50,000,000
Salvage Value							(5,000,000)
Total-Life Cycle Cost (net of all costs less salvage value)							**1,422,350,000**

Capital Project B						
Element				**Estimated Cost**		
Capital Project Cost	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Total**
Project Management	3,500,000	7,000,000	5,500,000	-		16,000,000
Design	17,000,000	13,000,000	-	-		30,000,000
Procurement	4,000,000	15,000,000	-	-		19,000,000
Construction	-	60,000,000	70,000,000	-		130,000,000
Title III	-	4,000,000	3,000,000	-		7,000,000
Transition to Ops	-			30,000,000		30,000,000
	24,500,000	99,000,000	78,500,000	30,000,000		232,000,000
Operations and Maintenance Cost						
Annual O&M (Assume 20 years @ $58,000,000/year)					58,000,000	1,160,000,000
Periodic Capital Replacements (Assume $20,000,000 each in operating year 7 and 14)				-		40,000,000
Revenue						
Annual income from excess production Assume $5M/year for operating life of plant					(5,000,000)	(100,000,000)
Final Disposition Cost						
Deactivation/Decommissioning						95,000,000
Salvage Value						-
Total-Life Cycle Cost (net of all costs less revenue)						**1,427,000,000**

A simple comparison of life-cycle cost indicates the alternatives are nearly equivalent, although Project A appears to be the more desirable from a cost standpoint, $1,422,350,000 for Project A versus $1,427,000,000 for Project B.

Conducting an LCCA for the two alternatives is then done in order to take into account the time value of money. Development of NPV figures for alternatives is based on the formula $PV = 1/(1+r)^t$ where r is the discount rate, and t is the number of years in advance when an expenditure is made, or a payment received. To illustrate the use of a PV factor, at a discount rate of 10 percent per year, the PV factor is 0.621 for year 5, meaning the present value of $1 spent or received at year 5 is $0.621.

> *Tip: Although present value tables are commonly available and useful, Appendix G provides a formatted spreadsheet that computes, from discount rate and time inputs chosen by the user, PV costs of future expenditures developed from the $1/(1+r)^t$ relationship.*

Comparing capital project A and B on an NPV basis begins with calculating the present worth of each expenditure or payment (salvage value of alternative A, revenue stream of alternative B) and summing them, as done in the Example 3-2.

Example 3-2
Calculating the Net Present Value

For illustrative purposes, a discount rate of 4% is used in this example.

Alternative Comparison at 4% Discount Rate

Alternative A																											
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	
Expenditure (M$)	36	57	56	98	70.4	50	50	50	50	70	50	50	50	50	70	50	50	50	50	70	50	50	50	50	50	50	
Salvage (M$)																										-5	
PV factor @ 4% discount rate	1.000	0.962	0.925	0.889	0.855	0.822	0.790	0.760	0.731	0.703	0.676	0.650	0.625	0.601	0.577	0.555	0.534	0.513	0.494	0.475	0.456	0.439	0.422	0.406	0.390	0.375	
PV	36	54.8	51.8	87.1	60.1	41.1	39.5	38	36.5	49.2	33.8	32.5	31.2	30	40.4	27.8	26.7	25.7	24.7	33.2	22.8	21.9	21.1	20.3	19.5	16.9	**922.67**

Alternative B																										
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	
Expenditure (M$)	24.5	99	78.5	30	58	58	58	58	58	58	78	58	58	58	58	58	58	78	58	58	58	58	58	58	95	
Revenue (M$)					-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5		
PV factor @ 4% discount rate	1.000	0.962	0.925	0.889	0.855	0.822	0.790	0.760	0.731	0.703	0.676	0.650	0.625	0.601	0.577	0.555	0.534	0.513	0.494	0.475	0.456	0.439	0.422	0.406	0.390	-
PV	24.5	95.2	72.6	26.7	45.3	43.6	41.9	40.3	38.7	37.2	49.3	34.4	33.1	31.8	30.6	29.4	28.3	37.5	26.2	25.2	24.2	23.3	22.4	21.5	37.1	**920.113**

As shown in the above table, Project B becomes the best cost alternative on a NPV basis, $920,113,000 to $922,670,000.

Another example of a LCCA is presented in Example 3-3. This example uses the LCCE for the hypothetical radiological laboratory that was used to illustrate LCCE principles earlier in this handbook (see data in Appendix C). Note that the estimate values used for this analysis do not include any allowances for estimate uncertainty or risk, as those topics will be discussed in Section 4.0 of this handbook. Section 4.0 will also describe the use of sensitivity analyses, with Example 4-6 providing the analysis for this example.

Example 3-3
LCCA Comparison of Alternatives

This example compares the costs to construct a new, more efficient radiological laboratory at an existing DOE site to replace an aging, less efficient laboratory. The LCCE elements for the new laboratory are as presented in Appendix C and in Examples 2-3 and 2-5.

Other elements and assumptions used for this analysis include the following items:

- The annual O&M costs for the existing facility are 25% higher than those of the new facility, because more work shifts will be needed in the existing facility to match the needed capacity (for which the new facility will be designed to achieve).
- It will be possible to continue to operate the existing facility for the remaining period needed, after some near-term modifications (which will not disrupt operations), and periodic upgrades over the remaining life that will be somewhat higher than the new facility will require.
- For the new facility option, the old facility final disposition (after a short S&M period) will need to be completed.
- It is assumed the S&M and final disposition costs will be the same for both facilities.

The results of the NPV calculations are presented in Appendix E.1. In summary, the analysis shows that, on a present value basis, it is slightly more economical to keep operating the existing facility ($358M) than it would be to design and construct a new, more efficient facility ($367M).

These results will be re-visited in Example 4-6 where risk and sensitivity analyses are considered.

Tip: Appendix H (as described in Section 5.0) provides an example of a management presentation of the results of an LCCA using the data from Example 3-3.

Occasionally, it will become apparent that certain costs related to a given alternate are likely to change. In such cases, it may be possible to conduct a revised comparative analysis that addresses only the components that have changed. However, it is always preferable to conduct a full comparative analysis of alternatives to ensure that all variables have been considered, and full documentation remains intact to support the program decision selection.

3.3 Program Analysis

This section discusses the composition and use of a life-cycle baseline as an instrument to manage a program comprising multiple projects and other elements, for example, laboratory support and research and development contracts. A program-level life-cycle cost baseline can be used to document a program's critical cost, schedule, and performance parameters, and express them in measurable, quantitative terms that must be met in order to accomplish the program's goals. By tracking and measuring actual program performance against this baseline, the program's management is alerted to potential problems, such as cost growth or requirements creep and can take early corrective action. As a point of reference, to develop budget estimates for operating programs, NNSA has implemented a planning, programming, budgeting, and evaluation (PPBE) process that provides a framework for the agency to plan, prioritize, fund, and evaluate program activities.

A program life-cycle baseline must be <u>comprehensive</u>. A formalized program WBS structure is required to provide a clear picture of what needs to be accomplished, where and when cross-cutting milestones must be achieved, and how the work will be done and to provide a basis for identifying resources and tasks for developing a cost estimate. Without a program-level work WBS, there is no assurance that a life-cycle cost estimate will capture all relevant costs, which can lead to cost overruns and schedule delays.

The program life-cycle baseline must be <u>well-documented</u>. Documentation is best when prepared as a single document to describe data sources and steps taken in developing the estimate—such as applying escalation rates, the basis for labor costs, sources of procurements, application of overhead, and other indirect costs—so that the estimate could be replicated by someone other than the preparers. Benefits and the methodology for assessing associated dollar values of benefits, attributed to each alternative, should also be documented, along with an explanation of how benefits support the mission need. Changes in baseline ground rules and assumptions should be evaluated promptly, and the affected cost estimates adjusted accordingly.

The program life-cycle baseline must be <u>accurate</u>. A formal system for tracking and reporting cost and schedule performance (earned value system) to update the estimate is essential to provide early identification of when, how much, and why the program cost more or less than planned.

The program life-cycle baseline must be <u>credible</u>. This is best accomplished by

- conducting an independent cost estimate to provide an unbiased test of whether the estimate is reasonable,
- providing a formal sensitivity analysis to examine the effects of changing assumptions and ground rules, and
- developing a risk and uncertainty analysis to assess variability in point estimates due to factors such as errors and estimator bias (see Section 4.0).

The basic concepts of LCCA are identical for use in evaluating both the elements of programs and projects. That is, LCCA always compares the NPV of competing alternatives.

Example 3-4
Programmatic LCCA

In the case of a DOE program consisting of multiple projects and locations, the LCCA process must, over time, address changing priorities and funding scenarios for the various projects that comprise a program, through an iterative process of re-assessing the LCCA as changes occur.

To illustrate the process of LCCA as applied to program analysis, this example envisions a program that designs and builds reactors at two locations, requires commercial R&D support and support from two national laboratories. Two programs are considered: Program X will transfer both reactors at the conclusion of a 4-year operating life to research facilities in exchange for a $10 million and $4 million fee, respectively. Program Y will construct two reactors at locations different from Program X. At the end of a four-year operating life, Program X will deactivate and decommission one reactor at a cost of $35 million, and turn the other over to a research institution for a $5 million fee.

Appendix E.2 shows the life-cycle cost summaries for these alternatives. As found in the appendix, Program X (at a cost of $738 million) appears to be more cost effective than Program Y ($740 million) on an as-spent basis. Comparing Programs X and Y on an NPV basis begins with calculating the present worth of each expenditure or payment (fees received for turning over Facilities A, B, and D to research institutions at the end of their 4-year operating cycles) and summing them, as done in Appendix E.3. The real discount rate recommended by OMB Circular No. A-94 (7 percent) is used in this example. From Appendix E-3, on an NPV basis, Program Y becomes the more economic configuration at an NPV value of $554.2 million, compared with $559.6 million for Program X.

3.4 Alternative Selection Considerations

Simply stated, the best solution among alternatives is the one with the lowest NPV. When the alternatives offer varying levels of benefits, or when placing a specific dollar value on benefits is difficult to assess, selection of the best alternative is more challenging. In general, the process for identifying benefits should include the following actions:

- Use a standard process to quantify the benefits and effectiveness of each alternative and document this process.
- Quantify the benefits and effectiveness resulting from each alternative over that alternative's full life cycle, if possible.
- Explain how each measure of benefit and effectiveness supports the mission need.

These actions should be included in the baseline documentation described in Section 3.3.

Example 3-5
Quantifying Benefits

A standard process to quantify benefits can take many forms. For example, to achieve an objective of eliminating unsafe conditions, completing a project quickly might be considered to have great value. The selection criteria could therefore propose a ranking process where each month sooner than the slowest alternative schedule that an alternative can be finished would deduct 1% of the PV of cost from that alternative. In so doing, the alternative with the lowest NPV (PV of cost less 1% x number of months finished sooner than longest schedule) would be chosen.

Assume Project A requires 28 months to complete, Project B requires 31 months, and Project C 23 months. Also assume the PV of life-cycle cost for Projects A, B, and C are \$236 million, \$230 million, and \$251 million, respectively. Then the NPV of each alternative can be represented as:

Project A: NPV_A = \$236 million – (31 − 28) × 1% × \$236 million = \$228.9 million

Project B: NPV_B = \$230 million (This is the alternative with the longest schedule.)

Project C: NPV_C = \$251 million – (31 − 23) × 1% × \$251 million = \$228.8 million

Thus, when the benefit of early finish is taken into account, despite having the highest cost PV, Alternative C becomes the most cost effective solution by a slight margin.

Tip: Providing a thorough explanation of the methodology used in assessing benefits to a program alternative not only clarifies the selection team's criteria, but also helps to allay concerns that the selection process was biased.

Example 3-6
Cost Avoidance Benefits

In another example, alternatives are assessed for competing projects considered for improving site security at a national laboratory. The projects are assumed to offer differing levels of benefits. The assessment therefore must find a means to measure a value for the unequal benefits to be achieved.

First, assume that the relative level of improved site security can be equated to the relative reductions in frequency and severity of undesirable events, such as unauthorized IT system access (external or internal), unauthorized physical access, and disasters affecting the site infrastructure (fire, flood, etc.) Each undesirable event can have specific costs associated with it, such as productivity losses resulting from virus attacks or from intruder caused stoppages, legal liability from unauthorized system access, etc. Relative benefits would comprise the sum of such costs avoided by each alternative solution.

Assume two competing site security improvement schemes, Project P and Project Q, are contemplated, with equivalent as-spent capital construction costs. Further, assume that both schemes can be brought into operation after a 3-year installation schedule; that is, through completion of all project phases, including procurement and construction.

The only difference in Projects P and Q lies in their ability to avoid “upset” costs. Their differing approaches (Project P is more heavily concerned with physical security and Project Q more with IT improvements) lead to differing types and amounts of cost avoidance benefits.

Assume that the benefits can be distilled to two types of cost avoidance; namely, avoidance of plant stand-downs caused by unauthorized intrusions, estimated to cost $2 million each, and IT compromises leading to total system outages and loss of data, estimated to cost $4 million each. Further, assume the plant currently experiences on average an unauthorized intrusion stand-down every 2 years and an IT compromise every 2 years.

Project P, with its focus on physical security is expected to yield one intrusion stand-down in the 5th year of its 10-year operating life. It is also expected to yield one IT compromise every 3 years, occurring in the 3rd, 6th, and 9th years of operating life.

Project Q, structured more heavily towards IT security, is expected to experience five intrusion stand-downs occurring in the 2nd, 4th, 6th, 8th, and 10th years of operating life, and one IT compromise in the 5th year of operations.

In Appendix E.4, PVs are calculated for the historical upsets costs over the operating life of the plant security improvements, compared to PVs of the expected upset costs under Project P and Q. As can be seen, the historical cost PV is expected to be $15.57 million if no improvements are made to plant security. Project P would result in $8.63 million in upset costs, and Project Q in $9.15 million. The savings produced by Project P would therefore be $15.57 million − $ 8.63 million = $ 6.94 million. Project Q would produce $15.57 million − $9.15 million = $6.42 million in avoided cost. Because Project P produces greater benefits (cost savings), it would be the best solution, if all other costs are equivalent, as assumed.

DOE Order 413.3B and its many attendant guides, including but not limited to Systems Engineering, Acquisition Strategy, and Cost Estimating, identify requirements and guidance pertaining to the analysis and comparison of alternatives. In addition, the General Accountability Office recently identified a draft "List of Generally Accepted Practices for the Analysis of Alternatives" which is contained in Appendix F.

3.5 LCCA Cost Tool

To assist the user in preparing NPV calculations of alternatives and to provide consistency in their formatting, Appendix G provides an Excel spreadsheet template that can be used to enter the variables of an LCCA. The template will yield a finished product that will be complete and consistent with other LCCAs. The spreadsheet is available as a live link by clicking the icon here:

Appendix G.xlsx

As provided, the appendix includes yearly life-cycle costs by project phase for two alternative programs. The yearly values represent the escalated, as-spent amount estimated by the user. There is also a single cell where the user enters the discount rate upon which to base the analysis. The spreadsheet then automatically calculates NPV for each alternative.

The Appendix is both an example of how the spreadsheet is used and the actual analytical tool for use in developing an LCCA. As the example, the spreadsheet depicts two program alternatives, A and B. Shaded areas of the spreadsheet contain entries made by a user. In this case, the user has selected 7 percent as the appropriate discount rate, and has entered annual as-spent cost estimates that amount to life-cycle costs of $639 million and $643 million for A and B, respectively. The spreadsheet then calculates NPV for each alternative, amounting to $431.5 million and $436 million for A and B, respectively. Users of the spreadsheet need simply delete the example figures and insert their own cost estimates in place of the sample figures.

4.0 UNCERTAINTY, RISK, AND SENSITIVITY ANALYSES

4.1 Overview

For any system, estimates of future LCCs are subject to degrees of uncertainty. The overall uncertainty is due to not only cost-estimating methods used but also uncertainties in program or system definition or technical performance. Although these uncertainties cannot be eliminated, it is useful to identify their associated risk issues and then attempt to quantify the degree of uncertainty as much as possible. This bounding of the cost estimate may be attempted through sensitivity analyses or a formal quantitative risk analysis.

Sensitivity analysis shows how estimated cost would change if one or more assumptions change. Typically, for high-cost elements, the analyst identifies the relevant cost drivers and then examines how costs vary with changes to the cost-driver values. For example, sensitivity analysis might examine how maintenance staffing varies with different assumptions about system reliability and maintainability values, or how system manufacturing labor and material costs vary with system-weight growth. In good sensitivity analyses, the cost drivers are not changed by arbitrary plus/minus percentages but rather by a careful assessment of the underlying risks. Sensitivity analysis is useful for identifying critical estimating assumptions, but it has limited utility in providing a comprehensive sense of overall uncertainty.

In contrast, quantitative risk analysis can provide an overall assessment of variability in the cost estimate. In quantitative risk analysis, selected factors (technical, programmatic, and cost) are described by probability distributions. When estimates are based on cost models derived from historical data, the effects of cost estimation error may be incorporated into the range of considerations included in the cost risk assessment. Risk analyses assess the aggregate variability in the overall estimate that stems from the variability in each input probability distribution—typically through Monte Carlo simulations. It is then possible to derive an estimated empirical probability distribution for the overall LCCE. This allows the analyst to describe the nature and degree of variability in the estimate.

Sensitivity and risk analyses have uses beyond addressing the uncertainty in cost estimates. These analyses can help managers understand what can go wrong with a program and thus focus appropriate attention on risk areas. The history of complex acquisitions indicates that cost growth and schedule delays can occur as a direct result of one or more of the following concerns:

- Immaturity of critical technologies at the start of development
- Inadequate understanding of design challenges at the start of development (often due to the absence of prototyping)
- Requirements uncertainty, instability, or creep
- Failure to acknowledge (or deal with) funding shortfalls
- Funding instability in the programming, budgeting, or appropriations processes
- Failure to detect (or deal with) unrealistic contractor cost proposals in competitive source selections (from either the prime contractor or major subcontractors)
- Excessive overlap in development and procurement schedules
- Inadequate understanding of software-development size and integration challenges

- Failure to stabilize the design by the time of the critical design review
- Failure to establish stable manufacturing processes by the time of early production.

Note that GAO's recommended "Twelve Steps of High Quality Cost Estimating" includes a Step 8, Conduct Sensitivity Analysis, and a Step 9, Conduct a risk and uncertainty analysis. DOE agrees that these steps are essential not only to producing quality project cost estimates and analyses, but even more importantly for the estimation and analysis of LCCs. This handbook presents and explains these two topics in reverse order—risk and uncertainly analyses first and then sensitivity analyses—because to perform a proper sensitivity analysis, the extent of uncertainty and risk as well as their key drivers and contributors must be known. This section of the handbook explains and discusses these steps.

Refer to the DOE *Risk Management Guide* (DOE G 413.3-7A) for more guidance on estimate uncertainty and the identification and analysis of risks, and to the *GAO Cost Estimating and Assessment Guide* for insights into best practices related to uncertainty and risk assessments as well as sensitivity analyses. The remainder of this section provides specific guidance and advice about uncertainty, risk, and sensitivity analyses as pertaining to the development of LCCEs and the conduct of LCCAs, without extensive repetition of the full guidance (which can be found in the aforementioned DOE and GAO reference documents).

4.2 Assessing and Quantifying LCCE Uncertainty

All estimates are, by definition, inherently uncertain. This uncertainty directly correlates to the degree of definition that underlies the estimate and to the rigor, methods, and approaches used to derive the estimate. LCCEs are no different; they are, by nature, uncertain values. Therefore, it is best to consider these estimates as ranges, or with an associated probability or level of confidence attributed to them. This approach is especially important when using LCCEs to inform the analysis and selection of an alternative or to establish future budget/funding needs and priorities.

> **The objective of quantifying estimate uncertainty for LCCEs is not to establish management reserve and contingency allowances. Rather, the objective is to ensure that the full range of potential LCCs is appropriately understood, to clearly inform the alternative comparison process and the use of such estimates when planning future budgets.**

To calculate the range or level of confidence associated with an LCCE, the following steps are recommended:

1. Summarize the LCCE and identify each major element. The level of detail/categories included should consider the uniqueness of the level of definition and estimate approach used to derive the estimate.
2. At a summary level, determine the potential range of variability to the point estimate (developed in accordance with the guidance found in Section 2.4 of this handbook and DOE G 413.3-21). This can be done by considering the range of accuracy levels by cost estimate type, as described in Table 2-1 and presented in Table 4-1 (taken from DOE G

413.3-21). These values are only intended to guide the subjective evaluation of expected accuracy and are best considered by a group of subject matter experts to attain consensus.

Table 4-1
Estimate Accuracy Ranges

Estimate Class	Expected Accuracy Range	
	Low	High
Class 5	-20% to -50%	+30% to +100%
Class 4	-15% to -30%	+20% to +50%
Class 3	-10% to -20%	+10% to +30%
Class 2	-5% to -15%	+5% to +20%
Class 1	-3% to -10%	+3% to +15%

Tip: The selection of the accuracy-range value should consider the element's complexity, technology considerations, estimating data sources, and other variables that influence the degree of uncertainty in the estimate.

Tip: To account for correlation of the parts of a cost estimate (those elements not truly independent of each other in terms of their accuracy and expected values), consider evaluating certain elements as percentages (or other parametric relationships) of other elements—for example, design engineering as a percentage of estimated construction costs. If this approach is followed, the percentages should be ranged in accordance with the assessment of uncertainty or estimate accuracy as well. (See Example 4-1.)

Example 4-1

Life Cycle Cost Estimate Uncertainty

Cost Element	Point Estimate	Basis of Estimate/Range	Low Range	High Range
Capital Project Cost				
Project Management	28,850,000	10% of all other costs; 5% to 15%	9,278,500	75,825,000
Design	40,000,000	20% of Procurement/Construction; 15% to 30%	21,000,000	90,000,000
Procurement	30,000,000	Class 4 Estimate; -30% to +50%	21,000,000	45,000,000
Construction	170,000,000	Class 4 Estimate; -30% to +50%	119,000,000	255,000,000
Title III	8,500,000	5% of Construction; 3% to 10%	3,570,000	25,500,000
Transition to Operations	40,000,000	20% of Procurement/Construction; 15% to 30%	21,000,000	90,000,000
	317,350,000		194,848,500	581,325,000
Operations and Maintenance Costs				
Annual O&M - 20 years	1,000,000,000	$50M per year; -10% to +25%	900,000,000	1,250,000,000
Periodic Capital Replacements	60,000,000	$20M every 5 years; -30% to +50%	42,000,000	90,000,000
Final Disposition Costs				
Deactivation/Decommissioning	50,000,000	Class 5 Estimate; -50% to +100%	25,000,000	100,000,000
Salvage Value	(5,000,000)	Class 5 Estimate; -50% to +100%	(2,500,000)	(10,000,000)
Total Life Cycle Cost	**1,422,350,000**		**1,159,348,500**	**2,011,325,000**

3. To calculate the overall range associated with the estimate, two alternative approaches are possible:
   a. If there are a minimal number of elements being considered (less than 10), summing the low and high estimates for each element will provide an overall

range for the total estimated LCC (as is done in Example 4-1). It should be noted, however, that this approach tends to overstate the total range and leads to a wider range than would be seen if a more probabilistic assessment is conducted—as described in the next alternative. (Example 4-2 further illustrates this point.)

b. For a more probabilistic assessment, and whenever there is a fairly large number of cost estimate elements (greater than 10), there should be a model constructed wherein each element is treated as a variable with its own probability profile. For most estimates, a triangular distribution is recommended, with the point estimate considered the "most likely" value and the low and high points derived from the application of the accuracy-range values selected based on Table 4-1 or on other parameters. These values can then be summed using a Monte Carlo simulation to derive an overall probability profile for the total LCCE.

Tip: Because the low- and high-end values are not in fact "absolutes," it is preferable to define those points as something like the 5% and 95% probability points of the distribution, rather than as 0% and 100% points.

Tip: Spreadsheet add-in software such as Crystal Ball®[19] and @Risk® are user-friendly tools that can be applied to create uncertainty and risk models and perform Monte Carlo simulations.

[19] Crystal Ball® is used for the examples provided in this document.

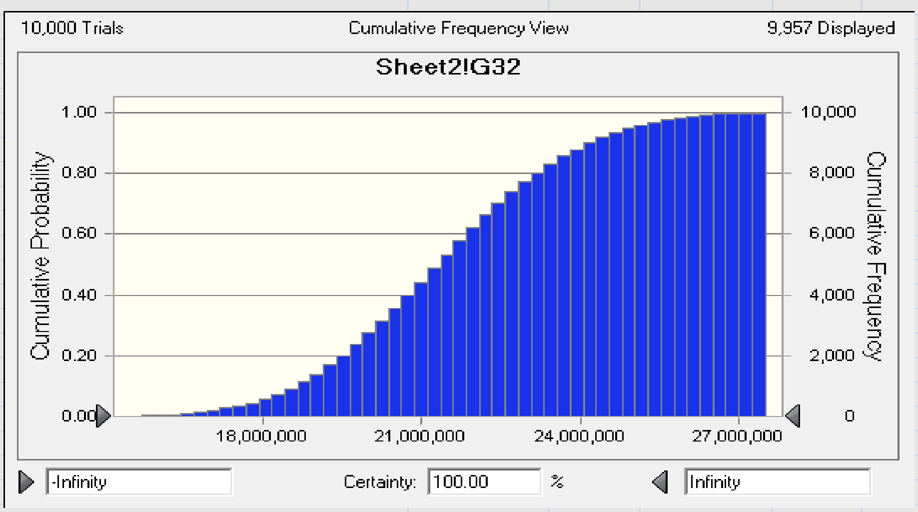
Example 4-2
LCCE Uncertainty using Monte Carlo Simulation

One alternative under consideration is the construction of a new facility to replace an aging, older facility. LCC must consider continued operations (and interim upgrades) of the existing facility until the new facility is in place, and then the ongoing operations, maintenance, upgrade, and eventual disposition of the new facility.

Life Cycle Cost Estimate for Alternative ($k)

Cost Element	Total Cost	Low Range		High Range	
Capital Investments					
New Facility Project Cost	4,820,000	-30%	3,374,000	+70%	8,194,000
Existing Facilities General Plant Equipment	246,927	-20%	197,542	+30%	321,005
Existing Facilities General Plant Projects	252,911	-20%	202,329	+30%	328,784
Facility Risk Review Requirements	77,283	-25%	57,962	+50%	115,925
Nuclear Facility Risk Reduction Project	67,589	-50%	33,795	+100%	135,178
Additional Deferred Maintenance Projects	110,934	-30%	77,654	+70%	188,587
Existing Facility Roofing Replacements	24,500	-20%	19,600	+30%	31,850
New Facility General Plant Equipment	458,963	-50%	229,481	+100%	917,926
New Facility General Plant Projects	1,119,547	-50%	559,774	+100%	2,239,095
New Facility Roofing Replacements	17,240	-30%	12,068	+70%	29,309
PIDAS Reduction	32,314	-50%	16,157	+100%	64,627
Operations and Maintenance					
Existing Facilities Operations	2,404,066	-15%	2,043,456	+20%	2,884,879
Existing Facilities Maintenance	677,146	-15%	575,574	+20%	812,575
New Facility Operations	4,324,455	-30%	3,027,118	+50%	6,486,682
New Facility Maintenance	1,540,474	-30%	1,078,332	+50%	2,310,711
Security	3,185,250	-30%	2,229,675	+50%	4,777,875
Final Disposition					
Existing Facilities Deactivation and Demolition	713,700	-50%	356,850	+100%	1,427,400
New Facility Deactivation and Demolition	562,098	-50%	281,049	+100%	1,124,196
Surveilance & Maintenance of Abandoned Facilities	95,527	-50%	47,763	+100%	191,053
Productivity Improvements					
PIDAS Deactivation	(1,252,800)	-30%	(876,960)	+70%	(2,129,760)
Total Cost of Alternative	**19,478,124**		**13,543,219**		**30,451,898**

Results of Monte Carlo Simulation, using triangular distributions (5%, most likely, 95%)



Range of values from simulation: at 10% confidence = $18.8 B; at 90% confidence = $24.3B

4.3 Identifying and Analyzing Risks Related to LCCEs and LCCAs

Risk management is important to project planning and execution. *DOE G 413.3-7A, Risk Management Guide* fully explores this topic and provides guidance on the full risk management process: risk planning, risk identification, risk analysis, risk handling, and risk monitoring and reporting. Chapter 14 of the *GAO Cost Estimating and Assessment Guide* explores the processes for assessing and analyzing estimate uncertainty (discussed previously in Section 4.1 of this handbook) and risk, and it presents best practices for such analyses.

Although the fundamental principles described in these two reference documents should be understood when deriving LCCEs and LCCAs, the LCCE/LCCA process needs to only consider risks from a limited perspective—that is, those events (threats that will add costs, or opportunities for lowering costs) that will directly affect the LCCE or potentially affect the LCCA should be identified and quantitatively analyzed.

> **Consideration of risks and their potential impact*s* on LCCs must carefully account for and segregate such influences separately from the inherent uncertainty of the base estimates—that is, risks represent events that may or may not happen (with an associated likelihood of occurrence) while uncertainty exists 100% of the time.**
>
> *Tip: Risk identification and definition is best done by project team members and subject matter experts working as a group, to facilitate a free interchange of ideas.*

A good starting point for risk identification is a careful review of the assumptions behind the LCCEs being considered. All estimates are based on a set of assumptions that must be clearly identified and explained. In addition, all assumptions may not be valid going forward—thus leading to a risk event that may affect the LCCE. It is appropriate to consider as “bounding assumptions” certain risks that may be unlikely to occur yet may have extremely consequential cost impacts. For project risk analyses, such bounding assumptions should be well documented and communicated and excluded from contingency/reserve allowance calculations. For an LCCE that will form the basis for an analysis/comparison of alternatives, however, even such bounding assumptions may need to be included in the risk analysis that supports such efforts.

In addition, when deriving an LCCE and LCCA, the following should be carefully considered and addressed:

- Risks identified by the project team, specifically those risks deemed “moderate” or “high,” that are used to derive either the proposed cost range or performance baseline for the project.
- Risks associated with future-year budgets and funding, which may affect project schedule or annual costs during the operations phase of the project or facility.
- Risks that will affect operations costs, such as contamination (radioactive, chemical, etc.), equipment reliability, capacity factors or production rates, staffing costs (hiring, retention, etc.), and utility availability and charges.

- Risks related to maintenance, including the variability and effectiveness of preventive maintenance programs, the extent of corrective maintenance required, and life-cycle and replacement needs of equipment and parts.
- Potential, but not certain, periodic upgrades or replacements (including their timing).
- Risks that may affect final disposition costs, such as regulatory requirements and the degree of contamination during operations.

When conducting LCCAs of alternatives, special care should be taken to identify and assess risks that may be specific to only one or more of the alternatives being considered. Accordingly, the risk identification process needs to be alternative-specific.

Once risks have been identified and fully defined and described, they need to be quantitatively analyzed. This process entails ascribing a likelihood of occurrence to each risk event (i.e., the probability the event will happen) and developing an estimate of the event's effect on LCCs if it does occur. These estimates should consider the possible effects of any possible risk mitigation actions; the analysis should consider "residual risk impacts" as described in DOE G 413.3-7A. Estimated impacts are inherently uncertain and thus are best developed as three-point estimates (best case, most likely, worst case) that can then be used to define a triangular (or other) probability distribution.

Tip: Care should be taken to identify risks consistently; if risks will arise at variable future points, then the cost impacts may need to be adjusted to reflect a consistent cost basis (present day, NPV, etc.), depending on the nature and purpose of the LCCE or LCCA.

After development of the risk likelihood of occurrence and the estimates of risk impacts, the process proceeds with the creation of a Monte Carlo simulation model similar to that done for estimate uncertainty (see Example 4-2).

The following charts are examples of an LCCE risk analysis (Example 4-3) and of the potential outputs of risk simulation models (Example 4-4), using the data from Examples 4-1 and 4-3, presented as:

- Risk impacts only with appropriate correlation of risks (Column A)
- Risk impacts only without appropriate correlation of risks (Column B)
- Total LCC to include risk impacts (with correlation) combined with results of uncertainty simulation for Example 4-1 obtained by adding two separate simulations (Column C)
- Total LCC to include risk impacts (with correlation) combined with results of uncertainty simulation for Example 4-1 obtained by using one simulation model that combines both elements (Column D).

Example 4-3
LCCE Risk Analysis

			Estimated Cost Impact ($M)		
	Risk Event	**Likelihood**	**Best**	**Most Likely**	**Worst**
Capital Cost (Project) Risks					
1	NQA-1 related costs not fully recognized. Vendor charges and installation issues cost significantly more than assumed in cost estimate.	Very High	5	15	30
2	Interfaces related to installation in a currently operating facility not adequately addressed. Productivity and schedule impacts during installation phase add to estimated project costs.	Moderate	5	10	15
3	Extent of needed refinements and improvements in existing systems and infrastructure not fully captured in project cost estimate, adding scope/costs.	Low	5	10	20
4	Issues encountered during Readiness Assessments result in added work scope and extend project schedule.	High	5	10	15
Operations Phase Risks					
5	Assumed production rates can not be achieved. Second shift operations required in some units to enable production targets and schedule to be met.	Moderate	50	100	200
6	Contamination event occurs, requiring extensive D&D and early replacement of certain equipment.	Low	10	15	20
7	Extensive staffing turnover leads to higher training costs and loss of productivity in operations.	Very Low	10	20	50
8	Assumed levels of corrective maintenance underestimated leading to higher costs.	Moderate	10	15	25
9	OPPORTUNITY: Production rates higher than assumed allowing facility life cycle schedule to be shortened.	Moderate	(100)	(50)	(25)
Final Disposition Risks					
10	Contamination during operations leads to higher D&D costs.	Low	15	25	50
11	OPPORTUNITY: Market for remaining materials and equipment better than assumed leading to higher salvage value benefits.	Moderate	(10)	(5)	(2)
12	Regulatory approvals not received as assumed resulting in significant change to needed end state and resulting higher D&D costs.	Low	25	50	100

Very Low: <10%; Low 10 %-< 30%; Moderate: 30% -<70%; High¨70% - <90%; Very High: >90%

Tip: In this example, the simulation model should reflect that Risks 6 and 10 are correlated; that is, if Risk 6 happens then Risk 10 will also happen. Similarly, Risks 5 and 9 need to be correlated; if Risk 5 happens then Risk 9 will ***not*** *happen and conversely.*

Tip: In a simulation model, the likelihood of occurrence can be modeled using the midpoint of the identified range or by using a uniform distribution that covers the full probability range; either approach is reasonable.

Example 4-4
Results of Simulation Models

	Risk Impacts Only ($M)		*Total LCC ($M)*	
Confidence	**A**	**B**	**C**	**D**
0%	-111.52	-103.57	1,141	1,253
5%	-51.95	-35.15	1,348	1,408
10%	-36.31	-14.55	1,388	1,446
15%	-24.85	3.86	1,416	1,472
20%	-15.04	18.60	1,440	1,498
25%	-5.50	29.00	1,463	1,521
30%	5.23	38.01	1,485	1,540
35%	17.25	47.02	1,509	1,559
40%	34.17	56.24	1,538	1,579
45%	58.70	67.15	1,574	1,599
50%	85.71	80.69	1,612	1,618
55%	111.36	94.31	1,649	1,638
60%	130.31	108.17	1,680	1,656
65%	146.45	122.08	1,709	1,675
70%	160.50	135.51	1,736	1,697
75%	174.53	149.17	1,764	1,719
80%	190.24	164.52	1,796	1,743
85%	208.80	183.06	1,834	1,771
90%	229.89	205.52	1,879	1,803
95%	259.30	236.25	1,939	1,853
100%	426.00	389.43	2,278	2,060

Observations (refer to highlighted cells)

- The 80% confidence impact of identified risks is much higher when risks are appropriately correlated as noted above (Column A vs. Column B results).
- The range of expected LCC is narrower when considered as a probability distribution, rather than adding the individual elements. (See 10% to 90% ranges in Column C or D results vs. the totals shown in Example 4-1.)
- The range of expected LCC is narrower when the uncertainty models and risk models are combined into a single simulation. (See 10% and 90% points in Column D vs. Column C.)

Tip: Appendix H (as described in Section 5.0) provides an example of a management presentation of the results of an LCCE using the data from Examples 4-1, 4-3, and 4-4.

4.4 Using Sensitivity Analyses for LCCEs and LCCAs

The *GAO Cost Estimating and Assessment Guide* (Chapter 13) states that, “As a best practice, sensitivity analysis should be included in all cost estimates because it examines the effects of changing assumptions and ground rules.” DOE endorses this best practice and believes it to be a vital element and consideration when developing LCCEs and conducting LCCAs and the alternative analyses that use those LCCA results. Only when decision makers fully understand the results of sensitivity analyses, combined with the results of the uncertainty and risk analyses previously described, can they hope to make the best choices—at either a programmatic or project level—among competing alternatives, execution strategies, project delivery vehicles, and portfolio optimization scenarios.

In effect, sensitivity analysis requires quantification of the effects from changing a specific single, individual assumption or value. This is done by changing one assumption or cost driver at a time while holding all other variables constant. There may also be cases when it is necessary or beneficial to examine the effect of multiple assumptions changing in relation to a specific scenario.[20] As noted in the GAO Guide, since uncertainty is prevalent early in a program or project design or development, it is likely that many of the assumptions made then will end up being inaccurate. Therefore, it is important to understand and be able to communicate the potential impact from variations in key assumptions and estimate cost drivers on LCCEs and the LCCAs that support alternative selections

GAO suggests a five-step process for a credible sensitivity analysis:

1. Identify key cost drivers, ground rules, and assumptions for sensitivity testing.
2. Reestimate the LCC by choosing one of the identified cost drivers or assumptions and varying it between two set amounts. The amounts chosen may represent maximum and minimum, various performance thresholds, or alternative assumptions.
3. Document the results.
4. Repeat Steps 2 and 3 until all factors identified in Step 1 have been independently tested.
5. Evaluate results to determine which drivers affect the cost estimate the most.

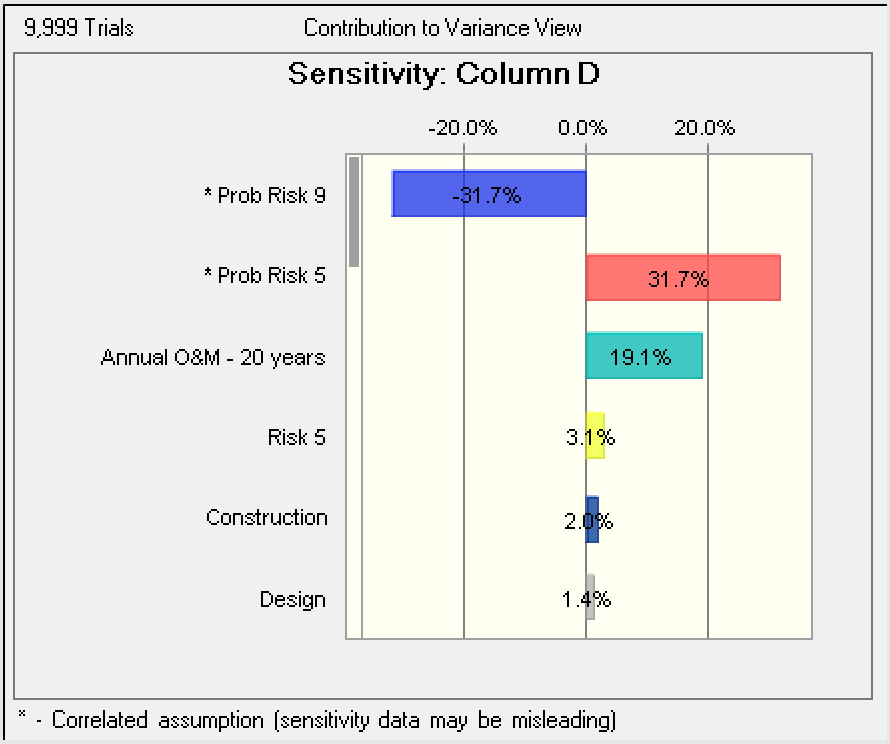
To identify the key cost drivers and critical assumptions, there are several recommended approaches:

- Look at the elements in the LCCE to identify areas of high cost, then attempt to isolate the subelements or assumed values that contribute to that cost estimate value.
- Carefully review all assumptions made and documented in the basis of estimate to isolate those assumptions that seem most uncertain or most critical to the viability of the resultant estimate.
- Look at the results of the sensitivity output from the Monte Carlo simulation model that assessed cost estimate uncertainty and risks (see Example 4-5). Such “tornado charts” illustrate the relative contribution of each simulation-model variable to the final cumulative probability profile. It should be noted, however, that the elements highlighted in such tornado charts may or may not be the most critical elements for a true sensitivity analysis and usually do not represent an all-inclusive listing of such elements.

[20] An example may be when comparing alternative acquisition strategies, for example a single design-build-operate turnkey approach compared to using separate engineering, procurement, construction, and operating contract vehicles.

Example 4-5
Tornado Chart

This chart shows the variables that contribute the most to the overall probability profile that combines cost estimate uncertainty and correlated risk events from Examples 4-1 and 4-3. (The probability profile data are presented in Column D of Example 4-4.)



Observations

- As can be seen, the most significant area highlighted by this model are the risks related to production levels (both a threat [Risk 5] and an opportunity [Risk 9]) and the base cost assumed/estimated for O&M over the 20-year life of the project.
- Accordingly, the sensitivity analysis should carefully consider the potential ranges of values that drive the annual O&M costs for this alternative.
- It may also be prudent to review critical cost drivers and assumptions related to the estimated costs for construction and design of the facility being proposed.

To determine the ranges of values that should be considered and addressed for a sensitivity analysis, it is recommended that actual historical data, available industry benchmarks, and other relevant data sources be researched and appropriately referenced. It is not a best practice to merely use arbitrary plus or minus values or other approaches that do not have a sound basis. However, in the absence of such historical/benchmark data, expert opinion of suitably qualified subject matter experts may be used.

For LCCAs that rely greatly on economic assumptions, it is critical to clearly test the results of the analysis (which alternative has the lowest NPV or economic value) as to the range of key assumed values used in such analyses. In particular, such elements as discount rates, escalation rates, interest rates, or market values for key commodities or utilities should be carefully reviewed and appropriately varied within some defined range to determine if variations in these elements can shift or alter the results of the analysis (and indicate a different alternative as the best choice).

Sensitivity analyses, and the resulting low and high cost, can also be useful when doing out-year budget planning and for establishing sound portfolio management strategies for programs.

In summary, GAO best practices for sensitivity analysis require the following:

- Well-documented sources that support the assumptions or factor ranges used in analyses.
- The sensitivity analysis is part of a quantitative risk assessment and is not based on arbitrary plus or minus percentages.
- Further examination of cost-sensitive assumptions and factors to see whether design changes should be implemented to mitigate risk.
- Sensitivity analysis should be used to create a range of best- and worst-case costs.
- Assumptions and performance characteristics listed in the technical baseline description, as well as ground rules and assumptions, are tested for sensitivity, especially those assumptions and characteristics least understood or at risk of changing.
- Results are well documented and presented to management for decisions. (This topic is covered in more depth in Section 5.0.)

Example 4-6
Sensitivity Analysis

The hypothetical radiological laboratory example used previously to demonstrate LCCE principles and used in the LCCA comparative analysis as Example 3-3, provides a good basis for illustrating how sensitivity analyses may further inform alternative selection and management decision-making. The following table presents the results from varying certain key drivers in the radiological laboratory example (see data provided in Appendix E-1). As can be seen, what may be reasonable variations in key assumptions or parameters can nevertheless change what is the least cost (in NPV terms) alternative (as highlighted in yellow).

Radiological Laboratory LCCA Example
Sensitivity Analysis

		Results of Calculations (NPV - $M)	
Driver	Variability	New Lab	Existing Lab
Base Case		***367***	***358***
Discount Rate	Lowered to 4%	478	480
	Increased to 10%	284	279
Existing Operating Costs	Gradual Detioration of operational efficiencies add 2%/year	372	422
	After mods, improve by 10% for remaining life	367	330
New Facility Operations	Achieve improvement in efficiency 10% lower than estimated annual costs	350	358
	Annual O&M costs 10% higher than estimated	384	358

In addition to conducting sensitivity analysis relative to these significant variables, it would be prudent to consider the potential impact of estimate uncertainties and (even more potentially influential) the impact of risks on the two alternatives being considered. For example:

- Is there a risk that it will not be possible to suitably modify and maintain the existing facility to make it last over the necessary operating period?
- Is the risk of potential contamination events—and therefore of resulting higher Final Dispostion costs—different between the two alternatives, and might that difference in risk affect the results of economic analysis?
- Are there potential variations in estimated schedules, either for design/construction of the new facility or for the operational period, that will change the economic analysis results?
- Is it possible that the estimated value and frequency of periodic upgrades for the new facility have been overestimated or that those for the existing faciliy are underestimated?

Tip: Appendix H (as described in Section 5.0) provides an example of a management presentation of the results of an LCCA using the data from Examples 3-3 and 4-6.

5.0 COMMUNICATING RESULTS OF LCCEs AND LCCAs

5.1 Presenting Results of LCCEs and LCCAs

This handbook has covered the steps to ensure proper development and documentation of LCCEs and LCCAs. Now, this handbook will discuss how to present the LCCE and LCCA results. Once the estimates have been derived and the analyses conducted, their results must be effectively communicated to appropriate levels of management in a way so that management clearly understands the estimates and analyses and can, in turn, ultimately approve them. This process of informing starts with a thorough presentation of the analysis, with an emphasis on effectively communicating the results of risk, uncertainty, and sensitivity analyses. In accordance with guidance promulgated by GAO[21], the key elements for communication are:

- Prepare a briefing that presents the documented LCCE, including an explanation of the technical and programmatic baseline and any uncertainties.
- Compare the LCCE with an independent cost estimate (ICE) and explain any differences. (An ICE or independent cost review is vital to providing consistent and professionally prepared cost estimates.)
- Compare the LCCE or ICE to the budget, using enough detail to easily justify the estimate by demonstrating its accuracy, completeness, and high quality
- Focus—logically—on the largest cost elements and cost drivers.
- Make the description of content clear and complete so that those unfamiliar with the topics can easily grasp and appreciate the competence exercised in deriving the estimate results.
- Make backup slides available to management so that it can ask more probing questions.
- Document and act on feedback from management.
- Request acceptance of the estimate.

Appendix H presents examples of one-page slides presented to management, which describe the (1) results of an LCCE and (2) data from an LCCA to support an alternative selection decision.

5.2 Documenting LCCEs and LCCAs

Thorough documentation is considered a best practice for high-quality LCCEs and LCCAs for several reasons:

- First, complete and detailed documentation is essential for validating and defending a cost baseline.
- Second, step-by-step documentation of cost-baseline details should be informative enough so that someone unfamiliar with the program or project in question can easily recreate or update the cost baseline. The basis of estimate should describe the design basis, the planning basis (significant features and components, proposed methods of accomplishment, and proposed project schedule), the risk basis, sensitivity analyses, supporting research and development requirements (important when new technologies

[21] GAO-09-35P, *GAO Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs*, May 2009.

are being considered for certain components, equipment, or processes), special construction or operating procedures, site conditions, the cost basis, and any other pertinent factors or assumptions that may affect cost. Sensitivity analyses that examine how changes to key assumptions and inputs affect the LCCE are a particularly important element of the documentation. Such analyses often give management an invaluable perspective as it makes decisions.

- Third, superior documentation helps when analyzing changes in program costs and contributes to the collection of pertinent cost and technical data that can be used to support future LCCE development.
- Finally, a well-documented LCCE is essential if an effective independent review is to ensure that the estimate is valid and credible. A well-documented LCCE also supports the reconciliation of any differences between the LCCE and ICE, improving understanding of the cost elements and their differences so that decision makers are better informed.

More and better information is expected to become available to adjust life-cycle baselines and their supporting basis of estimate documentation as changes occur between CDs or other life-cycle milestones. It is essential to actively maintain all baseline documentation. The latest and most realistic projections of cost and resource requirements are vital to facilitate effective program planning and to support communication with management as the baseline moves through successive levels of approval.

An accurate, well-documented LCCA is the lifeblood of program communication. It is a primary input into DOE decision-making and project approval CD process. Therefore, there should be full control exercised while maintaining LCCA documentation. Whenever possible, documentation should be organized into an indexed repository (either physical or digital), with an associated document control plan and a designated documentation engineer/administrator who will assure the documentation is adequately controlled. To the extent practical, the documentation index should be consistent with the program's WBS for ease of reference.

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ACRONYMS[22]

AACEI	Association for Advancement of Cost Engineering International
ABC	Activity-Based Costing
ACE	Applied Cost Engineering (team)
AE	Acquisition Executive
AFDCS	Active Facility Data Collection System
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFM	Cubic Feet per Minute
CSI	Construction Specification Institute
CD	Critical Decision
CER	Cost-Estimating Relationship
CMI	Corrective Measure Implementation
D&D	Decontamination and Decommissioning
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
EAC	Estimate at Completion
EC2	Environmental Cost Engineering Committee
ECAS	Environmental Cost Analysis System
ECES	Environmental Cost Element Structure
EE/CA	Engineering Evaluation/Cost Analysis
EM	DOE Office of Environmental Management
EMCBC	Environmental Management Consolidated Business Center
ER	Environmental Restoration
ES&H	Environmental, Safety, and Health
FSA	Functional Space Area
GAO	Government Accountability Office
ICE	Independent Cost Estimate
IDW	Investigation-Derived Waste
LCC	Life-Cycle Cost
LCCA	Life-Cycle Cost Analysis
LCCE	Life-Cycle Cost Estimate
LTM	Long-Term Management
M&S	Materials and Supplies
MAR	Material at Risk
MCACES	Micro-Computer-Aided Cost Estimating System
MII	MCACES II
NFA	No Further Action
NNSA	National Nuclear Security Administration
NPV	Net Present Value
O&M	Operations and Maintenance
OFA	DOE Office of Finance and Accounting
OMB	Office of Management and Budget
PACES	Parametric Cost Engineering System

[22] Definitions for these and other terms found in this document can be found in the DOE "Glossary of Terms Handbook."

PA/SI Preliminary Assessment/Site Inspection
PB Performance Baseline
PCM Parametric Cost Modeling
PPBE Program Planning, Budgeting, and Evaluation
PQM Parametric Quantity Modeling
PV Present Value
QA Quality Assurance
QTO Quantity-Take-Off
RA Remedial Action
RACER Remedial Action Cost Engineering and Requirements System
RCRA Resource Conservation and Recovery Act
RD Remedial Design
RFA RCRA Facility Assessment
RFP/CMS RCRA Facility Investigation and Corrective Measures Study
RI/FS Remedial Investigation and Feasibility Study
ROD Record of Decision
ROM Rough Order of Magnitude
RP Recommended Practice
S&M Surveillance and Maintenance
SF Square Foot
TCE Trichloroethylene
TPC Total Project Cost
UPB Unit Price Book
VE Value Engineering
VV&A Verification, Validation and Accreditation
WM Waste Management

APPENDIXES

Appendix A
Environmental Management/Restoration Life-Cycle Phases

Table A-1
Environmental Restoration Life-Cycle Phases

Phase	Life-Cycle Cost Work Breakdown Structure	Resource Conservation and Recovery Act (RCRA)	Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)
Phase 1	Mission Need Assessment	RCRA Facility Assessment (RFA)	Preliminary Assessment/Site Inspection (PA/SI)
Phase 2	Alternative Studies and Analysis	RCRA Facility Investigation and Corrective Measures Study (RFI/CMS)	Remedial Investigation and Feasibility Study (RI/FS)
Phase 3	Design	Remedial Design (RD)	Remedial Design (RD)
Phase 4	Procurement and Construction	Corrective Measure Implementation (CMI)	Remedial Action (RA)
Phase 5	Operations and Maintenance	O&M	O&M
Phase 6	Surveillance and Long-Term Maintenance	Long-Term Management (LTM)	Long-Term Management (LTM)
Phase 7	Final Disposition	Not Defined	Not Defined
Phase 8	Not Applicable	Program Level—Composite	Program Level—Composite

Phase Definitions
The environmental restoration (ER) phases shown in Table A-1 and defined below are taken from the ASTM E2150-2013 Standard Classification for Life-Cycle Environmental Work Elements ECES.

To improve cost estimating and cost management of environmental management projects in DOE, the Applied Cost Engineering (ACE) team of the Environmental Management (EM) program, in coordination with the Environmental Cost Engineering Committee, developed an ECES. This structure provides a common set of elements to describe the technical and administrative components (with related costs) for completed EM projects. The use of the ECES expedites cost collection for these projects and cost estimates for planned and active projects. It also provides the code of accounts to use in conjunction with a project WBS to better define projects. The suggested structure provides a common language to explain work and is used to codify historical projects.

The ACE team has also developed the ECAS to create and maintain a database of completed DOE environmental management projects. ECAS was developed to store and report data using the ECES structure and cost-driving parameters (secondary parameters) down to Level 3 elements (and lower [e.g., Level 5] if necessary). The system provides detailed reporting of ECAS data to enable users to develop estimates for future projects, establish benchmarks, and promote improved cost control and cost management. ECAS addresses ER, Waste Management

(WM), and Decontamination & Decommissioning (D&D) projects. Table A-1 shows only the ER project phase definitions.

Table A-1 shows the relationship between these ER LCC phases and the suggested LCC WBS (provided in this handbook's Appendix B). A notable difference between these schedules is that the ECES provides for a cross-cutting "Phase 8" (which is defined in the following bulleted list). Also, the ECES has reserved "Phase 7" for future use. The phases of the ECES (shown below) are positioned as Level 1. The middle and right-hand columns of Table A-1 relate these phases to, respectively, RCRA and CERCLA concepts and terms.

In general, the phases can be described as follows:

- **Phase 1: Assessment—**Assess and inspect site; prepare site inspection reports.

- **Phase 2**: **Studies—**Risk assessment, characterization and investigations, development and analysis of treatment or remediation options, and treatability studies.

- **Phase 3: Design—**Engineering design and preconstruction activities of treatment or remediation alternatives.

- **Phase 4: Procurement and Construction—**Construction and implementation of selected treatment or remediation alternatives. Includes start-up, but excludes all operations.

- **Phase 5: Operations and Maintenance—**Includes all O&M for the selected treatment or remediation alternatives. Phase ends when cleanup or waste treatment goals are met.

- **Phase 6: Surveillance and Long-Term Maintenance—**Operations have ceased or are not integral to selected treatment or remediation alternatives.

- **Phase 7:** This number is reserved for future use.

- **Phase 8: Program Management, Support & Infrastructure—**Includes overhead or program-wide activities required to implement environmental projects not specific to a distinct project. Phase 8 is used to represent those activities that are not readily segregated into Phases 1 through 6 (i.e., program-wide or cross-cutting activities). These activities are not generally associated with individual projects but are essential in order to plan and implement the collected projects that comprise the majority of the EM program. These activities apply to both government/owner and prime contractor activities.

Appendix B
Life-Cycle Cost Work Breakdown Structure

Life-Cycle Cost WBS

WBS	Element Description
1	**Total Project LCC**
1.1	**Mission Need Assessment**
1.1.1	Pre-Conceptual Planning
1.1.2	Mission Validation Independent Review
1.1.3	Mission Need Statement Document
1.1.4	Independent Cost Review
1.1.5	Program Requirements Document
1.1.6	Assessment of Safety-in-Design expectations
1.2	**Alternative Studies and Analysis**
1.2.1	Project Data Sheet and Funding Requirements
1.2.2	Project Reporting (PARS II) and QPRs
1.2.3	Alternative Concept Identification/Analysis
1.2.4	Conceptual Design Report (Preferred Alternative)
1.2.4.1	Conceptual Design
1.2.4.2	Documentation of High Performance and Sustainable Building provisions
1.2.4.3	Design Review
1.2.4.4	Code of Record
1.2.4.5	Conceptual Design Report
1.2.5	Acquisition Strategy (Document Development and Approval)
1.2.6	Preliminary Project Execution Plan
1.2.6.1	Develop/Approve Tailoring Strategy
1.2.6.2	Develop/Approve Preliminary Project Execution Plan
1.2.6.3	Assign/Charter Integrated Project Team
1.2.6.4	Develop Risk Management Plan
1.2.6.4.1	Complete Initial Risk Assessment
1.2.6.5	Cost and Schedule Range
1.2.7	ICE/ICR
1.2.8	Preliminary Hazard Report
1.2.9	Quality Assurance Program
1.2.10	Safeguards and Security Requirements Definition
1.2.11	NEPA Strategy
1.2.12	Project Data Sheet and Funding Requirements
1.2.13	Safety
1.2.13.1	Safety Design Strategy
1.2.13.2	Integrated Safety Management Plan
1.2.13.3	Conceptual Safety Design Report
1.2.13.4	Conceptual Safety Validation Report
1.2.14	Independent Project Review
1.2.15	R&D and Technology Development
1.3	**Design**
1.3.1	Management
1.3.1.1	Project Management
1.3.1.2	Design Oversight

1.3.2	Preliminary Design
1.3.2.1	Code of Record
1.3.2.2	System Descriptions
1.3.2.3	Design Studies/Tradeoff Analyses
1.3.2.4	Drawings
1.3.2.5	Specifications
1.3.2.6	Calculations
1.3.2.7	Cost Estimate
1.3.2.8	Schedule
1.3.2.9	Preliminary Design Report
1.3.3	Preliminary Design Review
1.3.4	Performance Baseline
1.3.4.1	Acquisition Strategy Update
1.3.4.2	Performance Baseline
1.3.4.2.1	Cost Baseline
1.3.4.2.2	Schedule Baseline
1.3.4.2.3	Key Performance Parameters
1.3.4.3	Project Execution Plan
1.3.4.3.1	Risk Management Plan
1.3.4.3.2	Funding Profile
1.3.4.3.3	Tailoring Strategy
1.3.4.3.4	Project Execution Plan Development/Approval
1.3.5	Project Management Plan
1.3.6	EIR/IPR/ICE
1.3.7	PDRI Analysis
1.3.8	TRA/TMP
1.3.9	EVMS
1.3.9.1	System Development
1.3.9.2	System Certification
1.3.10	Hazard Analysis Report
1.3.11	Quality Assurance Program
1.3.12	Preliminary Security Vulnerability Assessment
1.3.13	EIS/EA
1.3.14	Project Data Sheet
1.3.15	Technical Independent Project Review
	Safety
1.3.16	Safety Design Strategy
	Integrated Safety Management Plan
1.3.17	Preliminary Safety Design Report
1.3.18	Preliminary Safety Validation Report
1.3.19	Final Design
1.3.19.1	Code of Record
1.3.19.2	System Descriptions
1.3.19.3	Design Studies/Tradeoff Analyses
1.3.19.4	Drawings
1.3.19.5	Specifications
1.3.19.6	Calculations
1.3.19.7	Cost Estimate
1.3.19.8	Schedule
1.3.19.9	Final Design Report

1.4	**Procurement and Construction**
1.4.1	Project Management
1.4.2	Government Furnished Equipment
1.4.3	Procurement
1.4.3.1	Procurement Management
1.4.3.2	Long Lead Procurements
1.4.3.3	Equipment Procurement
1.4.3.3.1	Bid Solicitation
1.4.3.3.2	Bid Evaluation/Award
1.4.3.3.3.x	Vendor Costs (by individual or groups of equipment)
1.4.3.3.3.x.1	Vendor Design
1.4.3.3.3.x.2	Vendor Fabrication
1.4.3.3.3.x.3	Equipment Delivery
1.4.3.4	Bulk Material Procurement
1.4.3.4.1	Bid Solicitation
1.4.3.4.2	Bid Evaluation/Award
1.4.3.4.3.x	Vendor Costs (by individual or groups of materials)
1.4.3.5	QA/QC
1.4.3.5.1	Vendor Inspections/Surveillances
1.4.3.5.2	Commercial Grade Dedication Program
1.4.4	Construction
1.4.4.1	Construction Management
1.4.4.2	Construction
1.4.4.2.x	by Contract, Facility, System, etc. as appropriate
1.4.4.2.x.y	by control account, bid item, CSI, or other appropriate breakdown
1.4.5	Engineering Support during Construction (Title III)
1.4.6	Testing and Turnover to Operations
1.4.6.1	Acceptance Testing
1.4.6.2	Integrated System Testing
1.4.6.3	System Turnover Packages
1.4.6.4	Punchlist Items
1.4.7	Transition to Operations
1.4.7.1	Transition to Operations Plan
1.4.7.2	Operations Procedures
1.4.7.3	Operations Staff Training
1.4.7.4	Hazard Analysis Report
1.4.7.5	Environmental Management System
1.4.7.6	Documented Safety Analysis
1.4.7.7	Safety Evaluation Report
1.4.7.8	Code of Record
1.4.7.9	Management Assessment
1.4.7.10	Readiness Assessment/Operational Readiness Review
1.4.8	Project Completion
1.4.8.1	KPP Evaluation/Project Completion Criteria
1.4.8.2	Contracts Closeout
1.4.8.3	Contractor Evaluation Documents
1.4.8.4	Project Closeout Report (Final Cost Report)
1.5	**Operations and Maintenance**
1.5.1	Operations Management
1.5.1.1	Facility Management

1.5.1.2	Program/Production Management
1.5.2	Facility Infrastructure/Maintenance
1.5.2.1	Utilities
1.5.2.2	Housekeeping
1.5.2.3	Facility Maintenance
1.5.2.3.1	Preventive Maintenance
1.5.2.3.2	Corrective Maintenance
1.5.2.4	Infrastructure/Site Services
1.5.2.5	Supplies and Consumables
1.5.2.6	Minor Facility Upgrades and Replacements
1.5.2.6.1	Spare Parts
1.5.2.6.2	Upgrade/Replacement Projects
1.5.3	Program/Production Operations
1.5.3.1	Operations Staff
1.5.3.1.1	Shift Supervision
1.5.3.1.2	Core Operations Staff
1.5.3.1.3	Surge Operations Staff
1.5.3.2	Supplies and Consumables
1.5.3.3	Training/Professional Development
1.5.3.4	Operations Processes/Procedures
1.5.3.5	Equipment Maintenance/Repair
1.5.3.5.1	Tech Spec Surveillances
1.5.3.5.2	Preventive Maintenance
1.5.3.5.3	Corrective Maintenance
1.5.3.5.4	Repairs and Replacements
1.5.3.5.5	Spare Parts
1.5.3.6	Process Control System Operations
1.5.3.6.1	Hardware Procurement/Replacement
1.5.3.6.2	Software Procurement/Upgrade/Maintenance
1.5.3.6.3	IT Staff
1.5.4	Laboratory/Testing Operations
1.5.4.1	Laboratory Staff
1.5.4.2	Outside Services/Support
1.5.4.3	Laboratory Supplies/Consumables
1.5.4.4	Laboratory Maintenance/Repair
1.5.4.5	Laboratory Equipment Upgrades/Replacements
1.5.5	Safeguards and Security
1.5.5.1	Material Control & Accountability
1.5.5.2	Protective Workforce
1.5.5.3	Security Systems
1.5.5.3.1	Maintenance
1.5.5.3.2	Upgrades and Repairs
1.5.6	Environmental, Safety & Health
1.5.6.1	Program and Procedures
1.5.6.2	Surveillances and Inspection
1.5.6	Capital Upgrade/Replacement Projects
1.6	**Surveillance and Long-Term Maintenance**
1.6.1	Facility Shutdown/Deactivation
1.6.2	Stabilization
1.6.2.1	Asbestos Abatement

1.6.2.2	Fluid Removal
1.6.2.3	Hazard Reduction
1.6.2.4	Decontamination
1.6.2.5	Removal/Storage of Nuclear Materials
1.6.3	Equipment Relocations
1.6.4	Characterization and Surveys
1.6.5	Periodic Surveillances
1.6.6	Maintenance
1.6.6.1	Preventive Maintenance
1.6.6.2	Corrective Maintenance
1.6.7	Safeguards and Security
1.6.7.1	Access control
1.6.7.2	Security staff
1.6.7.3	Material Control & Accountability
1.6.8	Temporary Onsite Storage and Monitoring
1.7	**Final Disposition**
1.7.1	Decommissioning Planning
1.7.2	Decommissioning Engineering
1.7.3	Characterization and Surveys
1.7.4	Work Packages Execution
1.7.4.x	Specific work packages
1.7.5	Support Systems and Infrastructure
1.7.5.x	Specific items as appropriate
1.7.6	Waste Disposal
1.7.6.1	Packaging/Containerization
1.7.6.2	Transportation
1.7.6.3	Disposal Charges
1.7.7	Salvage
1.7.7.1	Equipment/Material Reclamation
1.7.7.2	Salvage Receipts
1.7.8	Site Restoration
1.7.9	Final Surveys and Releases
1.7.10	Regulatory Review and Approvals

Appendix C
Life-Cycle Cost Estimate Examples

Appendixes C.1, C.2, and C.3

These appendixes provide an example of an LCCE for a hypothetical radiological laboratory. Appendix C.1 presents the cost estimate data for Phases 1 through 4 of the life cycle. Appendix C.2 presents Phase 5 estimate data, and Appendix C.3 presents Phase 6 and Phase 7 example estimates.

The example used is for a hypothetical radiological research laboratory. The lab is a two-story 46,000-square-foot (SF) facility (a moderate size as DOE laboratories go). The facility will be built on a vacant lot with provision for utilities in the vicinity, within a current DOE operating site. For this example site is assumed to lack onsite disposal for low-level waste or mixed waste, but it does have the infrastructure for all safeguards and security as well as for program support. In this example, it is assumed that the project has received CD-1 approval and is ready to move into the preliminary design phase (Life Cycle Phase 3). In this example, only the conceptual design is available; therefore, the example uses parametric models and historical cost data and analogies for some cost elements.

The laboratory is assumed to be equipped with certain special laboratory equipment such as a 1000 CF Glove-box. It has two process areas: one area (12,303 SF) has negative ventilation; the other area (3,075 SF) does not need negative ventilation, but the area contains special laboratory equipment and (following strict safety protocol) includes an 827-SF exclusion zone. Table C.1-1 shows the makeup of functional space area for the example laboratory facility.

Appendix C.4

This Appendix provides an example of an LCCE for an ER project.

Appendix C.1
Laboratory Example Phases 1–4

Table C.1-1
Laboratory Building Parameters

FSA Name	Area (SF)	FSA %
Office Area-2	979	2.13%
Loading/Warehouse Area	1,627	3.54%
HVAC/Mechanical Area	1,627	3.54%
Change Rooms	407	0.88%
Corridor	8,022	17.44%
General Suport	4,474	9.73%
Analytical Lab Area	1,383	3.01%
Exclusion Zone	827	1.80%
Office Area-1	9,524	20.70%
Process Area Support	1,754	3.81%
Process Area-2	3,075	6.68%
Process Area-1 With Negative Ventilation	12,303	26.74%

Shell Parameters

Shell Quantity Parameters	Quantity	UOM
Footprint	23,022	SF
Perimeter	614	LF
Roof Area	23,022	SF
Floor to Floor Height Above Grade	21	FT
Floor to Floor Height Below Grade	0	FT
Exterior Wall Area	8,727	SF
Exterior Window Area	16,668	SF
Exterior Doors	7	EA
Floor to Ceiling Height Above Grade	10	FT
Floor to Ceiling Height Below Grade	0	FT
Number of Stairwells	2	EA
Number of Elevators	2	EA
Cooling Load	156	TN
Heating Load	4,831	MBH
Electrical Load	303	Amps

Table C.1-2
Laboratory Example Estimate of Phases 1 to 4

WBS	Element Description	Cost	Basis/Source
1.1	**Mission Need Assessment**	900,090	Actual Costs
1.2	**Alternative Studies and Analysis**	2,446,100	Actual Costs
1.3	**Design**	6,611,500	Table C-1.3
1.4	**Procurement and Construction**		
1.4.1	Project Management	6,628,700	Parametric
1.4.2	Government Furnished Equipment	500,000	Plug
1.4.3	Procurement		
1.4.3.1	Procurement Management	200,000	Parametric
1.4.3.2	Long Lead Procurements	1,500,000	Plug
1.4.3.3	Equipment Procurement	2,500,000	Plug
1.4.3.4	Bulk Material Procurement	-	With Construction
1.4.3.5	QA/QC	120,000	Parametric
1.4.4	Construction		
1.4.4.1	Construction Management	1,417,700	Parametric
1.4.4.2	Construction	28,354,000	Table C-1.4
1.4.5	Engineering Support during Construction (Title III)	1,701,200	Parametric
1.4.6	Testing and Turnover to Operations	1,984,800	Parametric
1.4.7	Transition to Operations	5,913,700	Parametric
1.4.8	Project Completion	1,767,700	Parametric
	Sub-Total Estimated Cost	62,545,490	
	Site Overheads/G&A	6,254,510	Assume 10% on Capital Project
	Total Estimated Cost	**68,800,000**	

Notes:
Contingency and Management Reserve Allowances not included
Costs are present day and do not include escalation allowance

Table C.1-3
Laboratory Example Design Cost Estimate (Phase 3)

WBS	Element Description	Quantity	U/M	Unit Hrs	Hours	Rate	Cost
1.3	**Design**						
1.3.1	Management						
1.3.1.1	Project Management				4,723	$ 150.00	708,400
1.3.1.2	Design Oversight				2,249	$ 125.00	281,100
1.3.2	Preliminary Design						
1.3.2.1	Code of Record	1	EA	200	200	$ 100.00	20,000
1.3.2.2	System Descriptions	8	EA	300	2400	$ 100.00	240,000
1.3.2.3	Design Studies/Tradeoff Analyses	6	EA	500	3000	$ 90.00	270,000
1.3.2.4	Drawings	200	EA	20	4000	$ 80.00	320,000
1.3.2.5	Specifications	30	EA	100	3000	$ 80.00	240,000
1.3.2.6	Calculations	100	EA	50	5000	$ 90.00	450,000
1.3.2.7	Cost Estimate	2	EA	500	1000	$ 100.00	100,000
1.3.2.8	Schedule	2	EA	400	800	$ 100.00	80,000
1.3.2.9	Preliminary Design Report	1	EA	600	600	$ 100.00	60,000
1.3.3	Preliminary Design Review	1	EA	300	300	$ 100.00	30,000
1.3.4	Performance Baseline						
1.3.4.1	Acquisition Strategy Update	1	EA	100	100	$ 100.00	10,000
1.3.4.2	Performance Baseline						
1.3.4.2.1	Cost Baseline	1	EA	500	500	$ 100.00	50,000
1.3.4.2.2	Schedule Baseline	1	EA	500	500	$ 100.00	50,000
1.3.4.2.3	Key Performance Parameters	1	EA	200	200	$ 100.00	20,000
1.3.4.3	Project Execution Plan						
1.3.4.3.1	Risk Management Plan	1	EA	600	600	$ 100.00	60,000
1.3.4.3.2	Funding Profile	1	EA	100	100	$ 100.00	10,000
1.3.4.3.3	Tailoring Strategy	1	EA	100	100	$ 100.00	10,000
1.3.4.3.4	PEP Development/Approval	1	EA	200	200	$ 100.00	20,000
1.3.5	Project Management Plan	1	EA	200	200	$ 100.00	20,000
1.3.6	EIR/IPR/ICE	1	EA	500	500	$ 100.00	50,000
1.3.7	PDRI Analysis	1	EA	100	100	$ 100.00	10,000
1.3.8	TRA/TMP						N/A
1.3.9	EVMS						
1.3.9.1	System Development	1	EA	200	200	$ 100.00	20,000
1.3.9.2	System Certification	1	EA	200	200	$ 100.00	20,000
1.3.10	Hazard Analysis Report	1	EA	400	400	$ 100.00	40,000
1.3.11	Quality Assurance Program	1	EA	500	500	$ 100.00	50,000
1.3.12	Preliminary Security Vulnerability Assessment	1	EA	100	100	$ 100.00	10,000
1.3.13	EIS/EA						N/A
1.3.14	Project Data Sheet	1	EA	100	100	$ 100.00	10,000
1.3.15	Technical Independent Project Review						N/A
	Safety						
1.3.16	Safety Design Strategy	1	EA	200	200	$ 100.00	20,000
	Integrated Safety Management Plan	1	EA	200	200	$ 100.00	20,000
1.3.17	Preliminary Safety Design Report						N/A
1.3.18	Preliminary Safety Validation Report						N/A
1.3.19	Final Design						
1.3.19.1	Code of Record	1	EA	300	300	$ 100.00	30,000
1.3.19.2	System Descriptions	8	EA	200	1600	$ 100.00	160,000
1.3.19.3	Design Studies/Tradeoff Analyses	6	EA	300	1800	$ 90.00	162,000
1.3.19.4	Drawings	400	EA	20	8000	$ 80.00	640,000
1.3.19.5	Specifications	35	EA	100	3500	$ 80.00	280,000
1.3.19.6	Calculations	200	EA	100	20000	$ 90.00	1,800,000
1.3.19.7	Cost Estimate	2	EA	500	1000	$ 100.00	100,000
1.3.19.8	Schedule	2	EA	400	800	$ 100.00	80,000
1.3.19.9	Final Design Report	1	EA	600	600	$ 100.00	60,000
	Total Estimated Design Cost				69,871		**$6,611,500**
Note:	***Values shown in above table are hypothetical and fictional and should not be interpreted as representing real or valid values.***						

Table C.1-4
Laboratory Example Construction Cost Estimate (Phase 4)

Radiological Research Laboratory						
		Material	**Labor**	**Equipment**	**SubBid**	**Total**
PRIMARY FACILITIES						
A	Substructure	$2,054,920	$2,087,519	$76,554	$0	$4,218,993
B	Shell	$2,956,894	$1,415,244	$74,613	$0	$4,446,751
C	Interiors	$2,605,984	$1,012,095	$3,707	$0	$3,621,786
D	Services	$5,615,242	$2,944,348	$27,176	$16,983	$8,603,749
E	Equipment & Furnishings	$3,334,552	$48,697	$0	$0	$3,383,249
	Marked Up Cost	$16,567,592	$7,507,903	$182,050	$16,983	24,274,528
SUPPORTING FACILITIES						
	Communications	$70,682	$36,232	$488	$0	$107,402
	Gas Distribution (Advanced)	$3,425	$6,480	$1,005	$0	$10,910
	Waste Water Collection (Advanced)	$14,668	$22,509	$4,349	$0	$41,526
	Water Distribution (Advanced)	$86,040	$76,112	$22,695	$0	$184,847
	Comparative Supporting Facilities:					
	Pavement:					$1,867,428
	Site Improvements:					$771,995
	Utilities:					$1,095,433
	Marked Up Cost					$4,079,541
	Estimated Construction Cost					**$28,354,069**

Appendix C.2
Laboratory Example Phase 5

Estimated Annual O&M Costs

Note: The data presented below is hypothetical and highly fictional in nature and should be viewed only as an example of the approach that can be used.

WBS	Element Description	Quantity	U/M	Rate	Annual Cost	Basis/Comments
1.5	**Operations and Maintenance**					
1.5.1	Operations Management					
1.5.1.1	Facility Management	4	FTE	200000	800,000	Staffing Plan
1.5.1.2	Program/Production Management	2	FTE	225000	450,000	Staffing Plan
1.5.2	Facility Infrastructure/Maintenance					
1.5.2.1	Utilities	1	LS		85,000	Scaled from historical data (.8 factor)
1.5.2.2	Housekeeping	1	LS		55,000	Scaled from historical data (.8 factor)
1.5.2.3	Facility Maintenance					
1.5.2.3.1	Preventive Maintenance	1	LS		1,500,000	Scaled from historical data (.8 factor)
1.5.2.3.2	Corrective Maintenance	1	LS		750,000	Assume 50% of PM
1.5.2.4	Infrastructure/Site Services	1	LS		2,000,000	Scaled from historical data (.8 factor)
1.5.2.5	Supplies and Consumables	1	LS		750,000	Scaled from historical data (.8 factor)
1.5.2.6	Minor Facility Upgrades and Replacements					
1.5.2.6.1	Spare Parts	1	LS		500,000	Scaled from historical data (.8 factor)
1.5.2.6.2	Upgrade/Replacement Projects	1	EA	100000	100,000	Based on historical experience
1.5.3	Program/Production Operations					
1.5.3.1	Operations Staff					
1.5.3.1.1	Shift Supervision	N/A				Covered under Laboratory Operations
1.5.3.1.2	Core Operations Staff	N/A				Covered under Laboratory Operations
1.5.3.1.3	Surge Operations Staff	N/A				Covered under Laboratory Operations
1.5.3.2	Supplies and Consumables	N/A				Covered under Laboratory Operations
1.5.3.3	Training/Professional Development	50	FTE	1000	50,000	Based on historical unit costs
1.5.3.4	Operations Processes/Procedures	N/A				Covered under Laboratory Operations
1.5.3.5	Equipment Maintenance/Repair					
1.5.3.5.1	Tech Spec Surveillances	N/A				Covered under Laboratory Operations
1.5.3.5.2	Preventive Maintenance	N/A				Covered under Laboratory Operations
1.5.3.5.3	Corrective Maintenance	N/A				Covered under Laboratory Operations
1.5.3.5.4	Repairs and Replacements	N/A				Covered under Laboratory Operations
1.5.3.5.5	Spare Parts	N/A				Covered under Laboratory Operations
1.5.3.6	Process Control System Operations					
1.5.3.6.1	Hardware Procurement/Replacement	1	LS		10,000	
1.5.3.6.2	Software Procurement/Upgrade/Maintenance	1	LS		500,000	
1.5.3.6.3	IT Staff	4	FTE	150000	600,000	2/shift, 2 shifts/day, 4 days/week
1.5.4	Laboratory/Testing Operations					
1.5.4.1	Laboratory Staff	40	FTE	150000	6,000,000	20/shift, 2 shifts/day, 4 days/week
1.5.4.2	Outside Services/Support	1	LS		500,000	Based on historical experience
1.5.4.3	Laboratory Supplies/Consumables	3300	Tests	1500	4,950,000	Based on historical unit costs
1.5.4.4	Laboratory Maintenance/Repair	1	LS		2,000,000	Based on historical experience
1.5.4.5	Laboratory Equipment Upgrades/Replacements	2	EA	500000	1,000,000	Based on historical experience
1.5.5	Safeguards and Security					
1.5.5.1	Material Control & Accountability	N/A				Will be at Existing Site w/o added requirements
1.5.5.2	Protective Workforce	N/A				Will be at Existing Site w/o added requirements
1.5.5.3	Security Systems	N/A				Will be at Existing Site w/o added requirements
1.5.5.3.1	Maintenance	N/A				Will be at Existing Site w/o added requirements
1.5.5.3.2	Upgrades and Repairs	N/A				Will be at Existing Site w/o added requirements
1.5.6	Environmental, Safety & Health	N/A				Will be at Existing Site w/o added requirements
1.5.6.1	Program and Procedures	N/A				Will be at Existing Site w/o added requirements
1.5.6.2	Surveillances and Inspection	N/A				Will be at Existing Site w/o added requirements
1.5.6	Capital Upgrade/Replacement Projects	1	EA	5000000	*	* Added every 5 years during operations
	Estimated Annual O&M Costs				**22,600,000**	

Appendix C.3
Laboratory Example Phases 6–7

Table C.3-1
Laboratory Example S&M Cost Estimate (Phase 6)

LCC WBS	Description		Total Cost	Basis
1.6	**Surveillance and Long-Term Maintenance**			
1.6.1	Facility Shutdown/Deactivation		$ 1,231,358	
1.6.1.1	D&D, Removal, Unattached Hazardous Materials (Removal Of Excess Chemicals)	395,389		Many RACER model inputs (data from analysis of PACES quantities)
1.6.1.2	D&D, Removal, Unattached Hazardous Materials (Removal Of Loose Materials)	186,036		Many RACER model inputs (data from analysis of PACES quantities)
1.6.1.3	D&D, Removal, Unattached Hazardous Materials (Removal Of Packaged Waste)	327,203		Many RACER model inputs (data from analysis of PACES quantities)
1.6.1.4	D&D, Conduit, Pipe & Ductwork (Utilities Isolation only)	322,730		Many RACER model inputs (data from analysis of PACES quantities)
1.6.2	Stabilization		$ 1,022,120	Estimate $22.22/SF for this type of facility - Assumes detailed walkdowns of an average of about 8,000 SF/20KSF building, including desks, cabinets, hoods, gloveboxes, and similar areas Assumes identification, characterization/sampling, and packaging of excess chemical items in the area
1.6.2.1	Asbestos Abatement			No suspected asbestos
1.6.2.2	Fluid Removal			
1.6.2.3	Hazard Reduction			
1.6.2.4	Decontamination			
1.6.2.5	Removal/Storage of Nuclear Materials			
1.6.3	Equipment Relocations		$ -	
1.6.4	Characterization and Surveys		$ 354,950	Assume 25% of full Characterization (WBS 1.7.3)
1.6.5	Periodic Surveillances		$ 731,584	80% of Estimate $19.88/SF Monthly surveys (3 year period), minor maintenance (e.g., doors, windows, rodent control, fire detection/suppression maintenance, low heating or freeze protection).
1.6.6	Maintenance		$ 182,896	20% of Estimate $19.88/SF
1.6.6.1	Preventive Maintenance			
1.6.6.2	Corrective Maintenance			
1.6.7	Safeguards and Security		$ -	Included with Hotel Load (Hotel Load is 41% to include Program Support, Security, Other Site Distributed Cost)
1.6.7.1	Access control			
1.6.7.2	Security staff			
1.6.7.3	Material Control & Accountability			
1.6.8	Temporary On-Site Storage and Monitoring			
	Subtotal		$ 3,522,908	
	DOE Site Overhead/G&A	40%	$ 1,409,093	
	Total Surveeillance and Maintenance		**$ 4,932,000**	

Table C.3-2
Laboratory Example Final Disposition Cost Estimate (Phase 7)

LCC WBS	Description		Total Cost	Basis
1.7	**Final Disposition**			
1.7.1	Decommissioning Planning		$ 116,188	Many RACER model inputs (data from analysis of PACES quantities)
1.7.2	Decommissioning Engineering		$ 1,394,253	Many RACER model inputs (data from analysis of PACES quantities)
1.7.3	Characterization and Surveys		$ 1,419,798	Many RACER model inputs (data from analysis of PACES quantities)
1.7.4	Work Packages Execution		$ 11,618,777	Many RACER model inputs (data from analysis of PACES quantities)
1.7.4.1	D&D, Removal, Attached Hazardous Materials	2,191,361		
1.7.4.2	D&D, Specialty Process Equipment W/ Glove Boxes	4,756,768		
1.7.4.3	D&D, Conduit, Pipe & Ductwork Removal	583,155		
1.7.4.4	D&D, Size Reduction	57,493		
1.7.4.5	D&D, Surface Decontamination	1,192,050		
1.7.4.6	Dismantlement and Demolition , Rad Contaminated Building	-		
1.7.4.7	Demolition, Buildings (Clean)	1,111,223		This Facility will be Demolished as Clean after Decontamination
1.7.4.8	D&D, Sampling And Analysis	1,726,727		
1.7.5	Support Systems and Infrastructure			Included with Hotel Load (Hotel Load is 41% to include Program Support, Security, Other Site Distributed Cost)
1.7.5.x	Specific items as appropriate			
1.7.6	Waste Disposal		$ 2,876,380	Derived for ECAS historical cost analysis
1.7.6.1	Packaging/Containerization			
1.7.6.2	Transportation			
1.7.6.3	Disposal Charges			
1.7.7	Salvage		$ -	
1.7.7.1	Equipment/Material Reclamation			
1.7.7.2	Salvage Receipts			
1.7.8	Site Restoration		$ 105,557	Based on PACES estimate for Site Restoration
1.7.9	Final Surveys and Releases		$ 982,161	Many RACER model inputs (data from analysis of PACES quantities)
1.7.10	Regulatory Review and Approvals			
	Subtotal		$ 18,513,114	
	DOE Site Overhead/G&A	40%	$ 7,404,886	
	Total Facility Disposition		**$ 25,918,000**	

Appendix C.4
Environmental Restoration Example

The earliest phase of an ER project is Discovery. Until a Phase 1 study (e.g., Preliminary Assessment/Site Inspection) is completed, a conceptual estimation cannot be performed. The first LCCE of the project is derived based on the results of this Phase 1 study; the Phase 1 study may in fact conclude that no further action is required. In such a case, a no Further Action (NFA) Record of Decision (ROD) would close out the project. Alternatively, the Phase 1 study may conclude that a Phase 2 study is required. Although only preliminary technical information is available at this stage, such information is likely sufficient to allow parametric models to be used to estimate the entire LCCE for the project.

Note: The phases in the sample WBS (Appendix B) directly correlate to a project-specific WBS. For instance, this ER project, the Phase 2 study (e.g., Remedial Investigation/Feasibility Study) correlates to the Alternative Studies and Analysis phase in the sample WBS. Appendix A further delineates such comparisons.

Example Project Scope
The Phase 1 study may uncover a trichloroethylene (TCE) plume at a site. This groundwater plum is approximately 0.5 acres in size. The presumptive remedy at this point would be to install a network of vertical air-sparging injection wells, piping, and necessary equipment, and to secure an electricity source for conducting air sparging to increase the flux of TCE into the gas phase in the source area. The ENVision cost model can be used; the model only requires three parameters to estimate a typical air-sparging project. They are:

- the size of the groundwater plume in acres (this example, 0.5 acres);
- soil type (this example, sand); and
- average well depth (this example, 48 feet).

The model will make several engineering assumptions including:

- Phase 3 Remedial Design
- Phase 4 Remedial Action including
  - installation of 41 air-sparging injection wells (each 2 inches in diameter) operating at 410 cubic feet per minute (CFM);
  - installation of soil vapor extraction wells (each 2 inches in diameter) using a hollow-stem auger generating 240 CFM of vapor for treatment in a catalytic oxidation system;
  - trailer-mounted blower system;
  - quantities of air, soil, and liquid samples;
  - Investigation-Derived Waste (IDW) disposal; and
  - construction project management.
- Phase 5 Operations and Maintenance, including
  - operating the installed systems,
  - sampling and analysis, and
  - project management.

The resultant parametric cost estimate for this scope is $1,263,646.
Of course, the better the definition of scope, the more accurate of an estimate that can be developed. There are several options (secondary parameters) that can be adjusted for each of the model elements listed above (e.g., direct push for well installation of the hollow-stem auger) as well as for elements that can be added or deleted.

In this example, we show that as this ER project is better defined, the scope significantly changes. Running the same ENVision model for the new project scope reduces the project cost by almost half because it removes the eight extraction wells and the catalytic oxidation system but adds in groundwater monitoring. The resulting cost estimate is $690,070.

Other models can be used to derive such estimates. To illustrate this, and provide comparative results, the same scope was estimated using the Remedial Action Cost Engineering and Requirements System (RACER) and Success.

To run them, RACER PCMs need more information, but that information should be available during a Phase 2 study. As the ER project matures, input data are perfected and the PCMs can be honed to create a defensible LCCE. By the time the project reaches the 33%-complete design point, these parametric estimates can (and should) be replaced with a bottoms-up estimate, using the quantity-take-off (QTO) method.

For comparison, we fast forward to a later point in the project and update the ENVision model and the RACER model, and then build a bottom-up estimate in Success Estimator. Each of these tools is discussed further in Section 2.5, LCCE Tools. Table C.4-1 lists the results.

Table C.4-1
LCCE for Same Scope Estimated Use Parametric and QTO Methods

Tool Name/LCC Phase	**Design**	**Construction**	**O&M**	**Total**
ENVision	$24,522	$489,831	$175,717	$690,070
RACER	$26,981	$352,261	$348,722	$727,964
Success	$54,700	$300,218	$345,181	$700,100

The LCCE totals are surprisingly close (less than 5% delta), given the nature of parametric models. They show that matching the exact scope and adjusting many secondary parameters can bring the parametric model into a closer range, but one cannot always count on such accuracy. As mentioned before, a Class 5 estimate like the first ENVision result is expected to be within the range of -30% to +50%. The estimates from Table C-4 represent more of a Class 2 check estimate result, thus the close grouping of total estimated costs is more reasonable.

Appendix D
Life-Cycle Cost Estimating Tools

PCMs are composed of cost-estimating relationships (CERs) where cost is the dependent variable and the cost-driving technical parameters are the independent (not correlated) variables. These CERs are the building blocks of a PCM. Ideally, PCMs are developed using statistical methods when there are sufficient data to define a distribution (central limit theory). In practice, however, PCMs are often engineered by estimating a low, a moderate, and a high case and then simulating the results to generate a relationship.

A model comprises many CERs. These CERs are integrated with each other to build the model; the PCM can also be referred to as an Integrated Cost Estimating Relationship (ICER) model. These PCMs are far more complex than just a series of CERs, and the models vary greatly because they estimate electronic components, software, infrared components, airframes, engines, etc., and make those estimations for the different life-cycle phases: program demonstration/validation, full-scale development, and production, operations, and support. The user needs only minimal cost information to build a credible budgetary cost estimate.

One of the advantages of the PCM over the parametric quantity model (PQM) (which is discussed in the following paragraphs) is that a PCM is much easier to maintain. As newly acquired historical project data might suggest a change to a CER, these data can be rolled into a new equation to update the CER. That is, the PCM can be updated by changing the curves to reflect new actual data rather than reengineering cost models, as must be done with the PQM. The ENVision (http://www.envisioncosts.com/) cost models are an example of this type.

PQMs are models where quantity, and not cost, is the dependent variable. A PQM is based on algorithms that select and quantify appropriate "assemblies" or items from a database to build up the estimate. The assemblies are the building blocks of a PQM; assemblies comprise one or more detailed unit-cost line items. These assemblies pull together labor, equipment, and material details. A cost assembly, for instance, is the summation of one or more individual line items. Each line item is a single catalogue item, the quantity of which is determined by the assembly. Take, for instance, the example of building a wall; line items such as mortar, brick, and steel constitute an assembly. This assembly is then quantified according to the number of linear feet of the wall—that is, for every linear foot of wall, proportionally more mortar, brick, and steel would be estimated.

One of the advantages of this type of model over the PCM is that a PQM is more readily translated into a definitive estimate once the project or program matures. Because they provide visibility to the assembly or line item level of detail, these data can be used in the definitive estimate directly in some cases. The RACER and PACES (http://www.aecom.com/) are examples of this type.

When sufficient design information is available, QTO is the most popular estimating method and is a typical estimating approach used in such cases. Many estimating tools use this estimating method. With the QTO method, the estimator takes the quantity of line items off of the design itself, hence the term "quantity-take-off." QTO estimating is often used in the construction industry. Work is divided into the smallest possible work increments and a "unit price" is established for each piece. These work increments are typically organized by MasterFormat. The unit price is then multiplied by the required quantity to find the cost for the increment of work. All costs are summed to obtain the total estimated cost. For example, the cost to erect a masonry wall can be accurately determined by finding the number of bricks required and estimating all costs related to delivering, storing, staging, cutting, installing, and cleaning the brick along with related units of accessories such as reinforcing ties, weep-holes, flashings, and the like. Accuracy is more likely to be affected by supply and demand forces in the current market.

Tools Information

What follows is some further information on these tools, including appropriate contact information for the vendors and suppliers of the tools.

NAME: **IDEAL**	
PURPOSE:	Parametric model development platform
DESCRIPTION:	IDEAL is a PCM development platform. IDEAL facilitates both the development and deployment of cost models. As such, IDEAL allows an estimator to integrate models from multiple sources into one estimate.
WEBSITE:	http://www.idealestimating.com
DEV/AUTHOR:	Enterprise Cost Solutions
AVAILABILITY:	Government & commercial
CERTIFIED TRAINERS:	Enterprise Cost Solutions Team Analysis, Inc. Envision Cost Solutions, LLC Booz Allen Hamilton

NAME: **ENVision Cost Models**	
PURPOSE:	Early phase environmental remediation estimating
DESCRIPTION:	More than 300 PCM cost models for estimating feasibility studies, site work, and the treatment, removal, containment, and/or disposal of waste including air, soil, water, sediment, free product, and building materials waste. ENVision models are used both before and during an engineering evaluation/cost analysis (EE/CA) or RI/FS, or are used to meet other estimating requirements for CERCLA and RCRA response actions.
LINKS:	http://www.envisioncosts.com
DEV/AUTHOR:	Envision Cost Solutions, LLC
AVAILABILITY:	Government & commercial
CERTIFIED TRAINERS:	Envision Cost Solutions, LLC Team Analysis, Inc. Booz Allen Hamilton

NAME: **Remedial Action Cost Engineering and Requirements (RACER)**	
PURPOSE:	Early Phase Environmental Remediation Estimating
DESCRIPTION:	110 PQM cost estimating modules for feasibility studies, site work, waste removal, containment, treatment, and disposal, capturing waste media including air, soil, water, sediment, free product, and building materials.
WEBSITE:	http://www.aecom.com/ then search for RACER
DEV/AUTHOR:	AECOM
AVAILABILITY:	Government & Commercial
CERTIFIED TRAINERS:	AECOM

NAME: **PACES Parametric Cost Engineering System**	
PURPOSE:	Early phase environmental remediation estimating
DESCRIPTION:	PACES is an integrated PC-based software system that prepares parametric cost estimates for new facility construction, renovation, and LCCA. PACES uses pre-engineered model parameters and construction criteria to accurately predict construction costs with limited design information.
WEBSITE:	http://www.aecom.com/ then search for PACES
DEV/AUTHOR:	AECOM
AVAILABILITY:	Government & commercial
CERTIFIED TRAINERS:	AECOM

NAME: **Success Estimator**	
PURPOSE:	Detailed estimating software
DESCRIPTION:	While Success provides a means to define custom logic to calculate quantities, it is principally a detailed QTO estimating system. Both the RS Means (sold separately) and UPB databases can be included.
WEBSITE:	http://uscost.net/CostEngineering.index.htm
DEV/AUTHOR:	R.I.B. (U.S. Cost)
AVAILABILITY:	Government & commercial
CERTIFIED TRAINERS:	R.I.B. (U.S. Cost) See link for schedule.

NAME: **MCASES II**	Micro-computer Aided Cost Estimating System (MCACES) Second Generation (MII)
PURPOSE:	Detailed estimating software
DESCRIPTION:	MII is principally a detailed QTO estimating system. Both the RS Means and UPB databases can be included.
WEBSITE:	http://www.miisoftware.com/
DEV/AUTHOR:	Project Time & Cost, Inc.
AVAILABILITY:	Government & commercial
CERTIFIED TRAINERS:	Project Time & Cost, Inc.

NAME: **RSMeans Cost Database**	RSMeans Reed Construction Data
PURPOSE:	Unit-cost database
DESCRIPTION:	Complete database of costs for commercial and residential construction with more than 75,000 unit prices and 25,000 building assemblies.
WEBSITE:	http://www.rsmeansonline.com
DEV/AUTHOR:	Reed Construction Data Inc.
AVAILABILITY:	Government & commercial
CERTIFIED TRAINERS:	Reed Construction Data Inc.

Appendix E
Life-Cycle Cost Analysis Examples

Appendix E.1
Data and Results for Example 3-3

Radiological Laboratory				
NPV Life Cycle Cost Estimate Comparison				
Build New Laboratory OR Upgrade and Continue Operations in Existing Laboratory				
(all estimate figures in present day dollars, real discount rate of 7% used)				
Cost to Build and Operate New, More Efficient Laboratory				
Phase	**Description**	**Estimate**	**Time Frame**	**NPV**
1	Mission Need Assessment	-	complete	-
2	Alternative Studies and Analysis	-	complete	-
3	Design	-	Years 1-3	-
4	Procurement and Construction	-	Years 3-5	-
5	Operations & Maintenance (includes periodic upgrades every 5 yrs)	467,000,000	Years 6-25	176,352,589
6	S&M	4,932,000	Years 26-28	800,355
7	Final Disposition	25,918,000	Years 29-30	3,523,940
	Continue Ongoing Ops of existing facility until the new lab is ready to operate ($28.25M/yr)	141,250,000	Years 1-5	115,830,578
	S&M of Existing Facility-- same amount as new facility estimate	4,932,000	Years 6-8	3,097,121
	Final Disposition of Existing Facility -- same amount as new facility estimate	25,918,000	Years 9-10	13,636,536
	ToTal	**669,950,000**		**313,241,119**
Continue Operations in Existing Laboratory				
Phase	**Description**	**Estimate**	**Time Frame**	**NPV**
1 - 2	Add sunk costs from New Lab	-	complete	-
3 - 4	Modify Existing Laboratory (Ph 3-4)-- Assume Ops can continue as mods are being made	10,000,000	Years 1-2	9,040,091
5	O&M - at current rate of $28.25M/yr Assume operations continue as mods are accomplished	706,250,000	Years 1-25	329,213,725
5	Upgrades -- add $7M every 5 years	28,000,000	7-13-17-22	11,263,345
6	S&M - assume same as new facility estimate	4,932,000	Years 26-28	800,355
7	Final Disposition - assume same as new facility	25,918,000	Years 29-30	3,523,940
	ToTal	**775,100,000**		**353,841,455**

Appendix E.2
LCC Data for Example 3-4

Comparative Life Cycle Costs of Two Science Programs

Program X

Element	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Total
Commercial R&D Studies	14,000,000	17,000,000	6,000,000									37,000,000
												-
Laboratory Support												-
Laboratory A	22,000,000	14,000,000	5,000,000	5,000,000	5,000,000	5,000,000	5,000,000	5,000,000	5,000,000	5,000,000		76,000,000
Laboratory B	9,000,000	17,000,000	3,000,000	3,000,000	3,000,000	3,000,000	3,000,000	3,000,000	3,000,000	3,000,000		50,000,000
												-
Capital Project Cost												-
Construct Facility A			12,000,000	85,000,000	120,000,000	60,000,000						277,000,000
Construct Facility B			-	16,000,000	78,000,000	46,000,000						140,000,000
												-
Operations Cost												-
Facility A							25,000,000	25,000,000	25,000,000	25,000,000		100,000,000
Facility B							18,000,000	18,000,000	18,000,000	18,000,000		72,000,000
Final Disposition												
Turnover Facility A											(10,000,000)	(10,000,000)
Turnover Facility B											(4,000,000)	(4,000,000)
Total all costs/benefits by year	45,000,000	48,000,000	26,000,000	109,000,000	206,000,000	114,000,000	51,000,000	51,000,000	51,000,000	51,000,000	(14,000,000)	**738,000,000**

Program Y

Element	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Total
Commercial R&D Studies	14,000,000	17,000,000	6,000,000									37,000,000
												-
Laboratory Support												-
Laboratory A	22,000,000	14,000,000	6,000,000	6,000,000	6,000,000	6,000,000	6,000,000	6,000,000	6,000,000	6,000,000		84,000,000
Laboratory B	9,000,000	17,000,000	3,000,000	3,000,000	3,000,000	3,000,000	3,000,000	3,000,000	3,000,000	3,000,000		50,000,000
												-
Capital Project Cost												-
Construct Facility C		6,000,000	14,000,000	63,000,000	91,000,000	26,000,000						200,000,000
Construct Facility D			13,000,000	26,000,000	78,000,000	46,000,000						163,000,000
												-
Operations Cost												-
Facility C							22,000,000	22,000,000	22,000,000	22,000,000		88,000,000
Facility D							22,000,000	22,000,000	22,000,000	22,000,000		88,000,000
												-
Final Disposition												-
Deactivation/Decommissioning Facility C											35,000,000	35,000,000
Turnover Facility D											(5,000,000)	(5,000,000)
Total all costs/benefits by year	45,000,000	54,000,000	42,000,000	98,000,000	178,000,000	81,000,000	53,000,000	53,000,000	53,000,000	53,000,000	30,000,000	**740,000,000**

Appendix E.3
NPV Analysis for Example 3-4

Comparative NPV of Two Science Programs

Program X

Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	
Expenditure (M$)	45	48	26	109	206	114	51	51	51	51	-14	738
Salvage (M$)												
PV factor @ 7% discount rate	1.000	0.935	0.873	0.816	0.763	0.713	0.666	0.623	0.623	0.582	0.543	
NPV	45.0	44.9	22.7	88.9	157.2	81.3	34.0	31.8	31.8	29.7	(7.6)	559.6

Program Y

Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	
Expenditure (M$)	45	54	42	98	178	81	53	53	53	53	30	740
PV factor @ 7% discount rate	1.000	0.935	0.873	0.816	0.763	0.713	0.666	0.623	0.623	0.582	0.543	

Appendix E.4
Data and Results for Example 3-6

PV Comparison of Historical Upset Costs to Expected Upset Cost of Project A and Project B at 7% Discount Rate

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	
Laboratory Experience	**Capital Constuction Phase**			**Operations Phase**										Total
Historical Costs of Upsets														
Intrusion Stand down					2		2		2		2		2	10
IT Compromised					4		4		4		4		4	20
Total As-Spent M$	0	0	0	0	6	0	6	0	6	0	6	0	6	30
PV factor @ 7% discount rate	1.000	0.935	0.873	0.816	0.763	0.713	0.666	0.623	0.623	0.582	0.543	0.509	0.475	
PV	**0**	**0**	**0**	**0**	**4.578**	**0**	**3.996**	**0**	**3.738**	**0**	**3.258**			**15.57**
Project P														Total
Expected Upset Costs														
Intrusion Stand down								2						2
IT Compromised						4			4			4		12
Total As-Spent M$	0	0	0	0	0	4	0	2	4	0	0	4	0	14
PV	**0**	**0**	**0**	**0**	**0**	**2.852**	**0**	**1.246**	**2.492**	**0**	**0**	**2.036**	**0**	**8.626**
Project Q														Total
Expected Upset Costs														
Intrusion Stand down				2		2		2		2		2		10
IT Compromised							4							4
Total As-Spent M$	0	0	0	2	0	2	4	2	0	2	0	2	0	14
PV	**0**	**0**	**0**	**1.632**	**0**	**1.426**	**2.664**	**1.246**	**0**	**1.164**	**0**	**1.018**	**0**	**9.15**

Appendix F
GAO List of Generally Accepted Practices for the Analysis of Alternatives

GAO 's List of Generally Accepted Practices for the Analysis of Alternative Process Generally Accepted Practice	
General Principles for the Analysis of Alternatives Process	
Who conducts analysis	
1	The team who conducts the AOA (the team") must contain members with various areas of expertise including, at a minimum, technical expertise, project management, cost estimating and risk management.
Create a Study Plan	
2	The team should create a plan for identifying and selecting alternatives, including proposed methodologies and assessment criteria, before beginning the AOA process.
Study Time Frame	
3	The team should be given enough time to complete the AOA process to ensure a robust and complete analysis.
Determine Mission Functional Need and Mission Requirements	
4	The customer should define the mission need and functional requirements without a pre-determined solution in mind.
5	The customer should define functional requirements based on the mission need.
Document the Analysis	
6	The team should document all steps taken to identify, analyze and select alternatives in a single document.
Other General Principles	
7	The team should document and justify all assumptions and constrains used in the analysis.
8	The team should conduct the analysis without a pre-determined solution in mind.
Identifying Alternatives	
9	The team should identify and consider a diverse range of alternatives for meeting the mission need.
10	The team should describe alternatives in sufficient detail to allow for robust analysis.
11	The team should include one alternative representing the status quo to provide a basis of comparison among alternatives.
12	The team should screen the entire list of alternatives before proceeding, eliminate those that are not viable, and document the reasons for doing so.
Analyzing Alternatives	
Cost Analysis	
13	The team should develop a life-cycle cost estimate for each alternative considered, including all costs from inception of the project through design, development, deployment, operation, maintenance and retirement.
14	The team should develop a life-cycle cost estimate for each alternative analyzed that includes a confidence interval or range, and not solely a point estimate.
15	The team should develop cost estimates using the appropriate discount rate and explain why they chose that specific rate.
Effectiveness Analysis	
16	The team should use a standard process to quantify the benefits/effectiveness of each alternative and document this process.
17	The team should quantify the benefits/effectiveness resulting from each alternative over that alternative's full life cycle, if possible.
18	The team should explain how each measure of benefit/effectiveness supports the mission need.
Risk and Sensitivity Analysis	
19	The team should identify and document significant risks and mitigation strategies for each alternative.
20	The team should test and document the sensitivity of both the cost and benefit/effectiveness estimates for each alternative to risks and changes in key assumptions.
Review	
21	A party independent of the project's chain of command should review the AOA process to ensure, at a minimum, that 1) a sufficient range of alternatives have been considered, 2) cost and benefit/effectiveness estimates are justifiable, 3) risk and sensitivity analysis have been conducted and incorporated into the cost and benefit/effectiveness estimates.
Selecting a Preferred Alternative	
Selection Criteria	
22	The team or decision maker should define selection criteria based on the mission need.
23	The team or decision maker should weight the selection criteria to reflect the relative importance of each.
Compare Alternatives	
24	The team or decision maker should compare alternatives using net present value, if possible.

Appendix G
Life-Cycle Cost Analysis Spreadsheet Template

Appendix G

Spreadsheed to Calculate PV for User input of Discount Rate and Annual As-spent Cost

Alternative Comparison at User Defined Discount Rate-Enter Rate Here		7%																								
Alternative A																										
Year		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	
Capital Construction (M$) (Phases 1-4)	U s	36	57	56	98	72																					
Ops & Maint (Phase 5)	e						50	50	50	50																	
Surveillance & Long-term Maintenance (Phase 6)	r										10	10	10	10	10	10	10	10	10	10	10	10	10	10			
Final Disposition (Phase 7)	I																								12	8	
Benefits-Revenue	n						-10	-10	-10	-10																	
Benefits-Salvage	p																										
Benefits-Other	u t																										
As-Sspent LCC		36.00	57.00	56.00	98.00	72.00	40.00	40.00	40.00	40.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	12.00	8.00	639.00
PV		36.00	53.27	48.91	80.00	54.93	28.52	26.65	24.91	23.28	5.44	5.08	4.75	4.44	4.15	3.88	3.62	3.39	3.17	2.96	2.77	2.58	2.42	2.26	2.53	1.58	431.48
Alternative B																											
Year		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	
Capital Construction (M$) (Phases 1-4)	U s	24.5	99	78.5	64	58	47																				
Ops & Maint (Phase 5)	e							36	36	36	36	36															
Surveillance & Long-term Maintenance (Phase 6)	r												12	12	12	12	12	12	12	12	12	12	12				
Final Disposition (Phase 7)	I																							16	4		
Benefits-Revenue	n							-12	-12	-12	-12	-12															
Benefits-Salvage	p																										
Benefits-Other	u t																										
As-Sspent LCC		24.5	99	78.5	64	58	47	24	24	24	24	24	12	12	12	12	12	12	12	12	12	12	12	16	4		643.00
PV		24.5	92.52	68.56	52.24	44.25	33.51	15.99	14.95	13.97	13.05	12.20	5.70	5.33	4.98	4.65	4.35	4.06	3.80	3.55	3.32	3.10	2.90	3.61	0.84		435.95

Appendix H
Management Presentation Examples

Example 1 – Results of LCCE for Example Project (see Examples 4-1, 4-3, and 4-4)

Project X Life Cycle Cost Estimate ($M)

Cost Element	Point Estimate	Low Range	High Range
Capital Project Cost	317.4	194.8	581.3
Operations and Maintenance	1,060.0	942.0	1,340.0
Final Disposition Costs	45.0	22.5	90.0
Total Life Cycle Costs	**1,422.4**	**1,159.3**	**2,011.3**

Key Assumptions

•Capital Project costs based on Class 4 estimate with parametric adders and ranges.
•O&M estimate is derived by scaling from comparable facility; includes periodic capital replacements.
•Final Disposition assumes immediate D&D with some limited salvage value.

Major Areas of Risk

•NQA-1 issues impacting procurement and construction
•Readiness Assessment challenges
•Assumed production rates may not be achieved; but if bettered represent opportunity
•Salvage value market may represent opportunity

Overall range based on Monte Carlo simulation, from 10% to 90% confidence:
$1.4 B to $1.8 B

Example 2 – Results of LCCA for Laboratory Example

Radiological Laboratory -- Potential Alternatives

Design/Construct New Lab

- Estimated LCC = $739 M
- **PV of LCC = $367 M**

Key Assumptions

- Existing lab will operate until new facility is ready
- New facility will achieve 25% savings in annual O&M costs
- Operating efficiency will remain unchanged over 20 year operating life

Continue to Use Existing Lab

- Estimated LCC = $779 M
- **PV of LCC = $358 M**

Key Assumptions

- It is possible to operate existing facility for remaining needed life after making some near term modifications
- It will be necessary to work more shifts to achieve needed capacity to match new facility, with higher annual O&M
- Facility will be able to operate while modifications are made.

Sensitivities

- Lower discount rate (4% vs. 7%) shifts advantage to new lab
- If existing operations become even less efficient, advantage shifts to new lab
- Higher discount rate, or improved operations in existing lab, makes continued use of existing lab even more attractive
- If new lab O&M costs are under-estimated, or grow, keeping existing lab more economical
- Risks to consider:
  - Can existing facility last?
  - Are potential risks from contamination different for existing lab vs. new?
  - Have potential upgrades, and their frequency, been accurately estimated?
  - Can the planned schedule for modifying existing, or constructing new lab be achieved?