EPA/600/R-99/100
April 2001

Cost Evaluation Strategies for Technologies Tested Under the Environmental Technology Verification Program

by

Arun Gavaskar
Lydia Cumming

Battelle
Columbus, OH 43201-2693

Contract No. 68-C7-0008
Work Assignment No. 3-16

for

Project Officer, George Moore
Work Assignment Manager, Richard Scharp

NATIONAL RISK MANAGEMENT RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OH 45268

Printed on Recycled Paper

Notice

The U.S. Environmental Protection Agency through its Office of Research and Development funded the research described here under Contract No. 68-C7-0008, Work Assignment No. 3-16. The work was supported under the U.S. EPA Environmental Technology Verification (ETV) Program. This cost evaluation strategy report has been subjected to U.S. EPA's peer and administrative review, and has been approved for publication as an U.S. EPA document.

Foreword

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

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

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

E. Timothy Oppelt, Director
National Risk Management Research Laboratory

Abstract

The objective of this document is to provide a general set of guidelines that may be consistently applied for collecting, evaluating, and reporting the costs of technologies tested under the Environmental Technology Verification (ETV) Program. Because of the diverse nature of the technologies and industries covered in this program, each ETV pilot has the flexibility for any of the following options to be used:

- No cost evaluation
- Itemization of costs
- Estimation of capital investment and operation and maintenance (O&M) costs
- Calculation of total annualized cost, simple payback period, or present value.

The four cost options are incremental; each successive option builds on and incorporates all of the elements of the previous options to provide a comprehensive cost evaluation.

One option for pilots with limited resources or other restrictions is to not evaluate costs. In the second option, all cost items are identified and quantified, without assigning monetary (dollar) values. The cost items are reported in two categories, capital investment and operation and maintenance (O&M) costs.

In the third option, the cost evaluation process is taken one step further. All the capital and O&M items are identified, quantified, and assigned dollar values. In the fourth option, the total impact of the technology on the user is calculated. The fourth option also facilitates the comparison of the ETV technology with a baseline or competing technology. Assessing the total impact of a technology typically involves the calculation of either total annualized cost, simple payback period, or present value.

A comprehensive reporting format, which includes cost evaluation objectives and data collection methods, estimates of capital investment and O&M costs, cost analysis, list of assumptions, technical factors affecting costs, and intangible benefits and/or disadvantages of the technology, is recommended.

Contents

Appendices

Figure

Tables

Acronyms and Abbreviations

BTU	British thermal units
DOE	Department of Energy
DSF	dual-stage pressure filtration
ECHOS	Environmental Cost Handling Options and Solutions
ETV	Environmental Technology Verification
EvTEC	Environmental Technology Evaluation Center
FCI	fixed capital investment
gpm	gallons per minute
kWh	kilowatt-hours
NRMRL	National Risk Management Research Laboratory
NTU	nephelometric turbidity unit(s)
O&M	operation and maintenance
ORD	Office of Research and Development
PV	present value
QA	quality assurance
QA/QC	quality assurance/quality control
U.S. EPA	United States Environmental Protection Agency

Acknowledgments

This document was prepared under the direction of George Moore, project officer, National Risk Management Research Laboratory (NRMRL) in Cincinnati, Ohio; and Richard Scharp, Work Assignment Manager (WAM), NRMRL. The authors would like to acknowledge the special efforts of John Abraham, NRMRL; Jeff Adams, NRMRL; and Lauren Drees, NRMRL, who provided considerable help in reviewing the document and providing guidance and technical support. Special acknowledgment is given to the ETV pilot managers, who provided comments and suggestions during the creation of this document.

The authors appreciate the contribution of Penelope Hansen, ETV Program Director, for recognizing and supporting the need for a uniform cost evaluation strategy for assessment of ETV technologies.

1. Introduction

This document contains the general methodology for estimating application costs for technologies tested under the United States Environmental Protection Agency's (U.S. EPA's) Environmental Technology Verification (ETV) Program.

1.1 ETV Program Description

The U.S. EPA's Office of Research and Development (ORD) initiated the ETV Program in 1994. The ETV Program is designed to accelerate the development and use of environmentally friendly technologies through objective verification and reporting of technology performance. The goal of the program is to provide potential purchasers and regulators with an independent and credible assessment of what they are buying and permitting. The ETV Program is implemented through 12 pilot programs. These pilots are in various stages of development, and each pilot program (commonly referred to by ETV participants as a "pilot") focuses on a specific environmental area of interest. (The only exception is the Environmental Technology Evaluation Center [EvTEC] pilot, which is independent and does not focus on a specific area of interest.)

Table 1-1 lists the various pilots, U.S. EPA project officers, ETV partners, and ETV partner managers and contacts. The U.S. EPA is responsible for auditing and oversight of these partner organizations, as appropriate, to ensure the credibility of the verification process and data. The ETV partners are responsible for evaluating the performance of the vendors' technologies based on testing and quality assurance (QA) protocols developed with input from stakeholders. Stakeholders consist of representatives of all verification customer groups: buyers and users of technology, developers and vendors,

Table 1-1. U.S. EPA Project Officers, ETV Partners, and ETV Partner Contacts for Each ETV Pilot

ETV Pilot	U.S. EPA Project Officer	ETV Partner	ETV Partner Contacts
Drinking Water Systems	Jeff Adams	NSF International	Bruce Bartley
Site Characterization and Monitoring	Eric Koglin	Oak Ridge National Laboratory	Roger Jenkins Amy Dindal
		Sandia National Laboratory	Wayne Einfeld
EvTEC	Norma Lewis	Civil Engineering Research Foundation	William Kirksey
Pollution Prevention: Coatings and Equipment	Mike Kosusko	Concurrent Technologies	Brian Schweitzer Vikki Miller
Indoor Air Products	Les Sparks	Research Triangle Institute	David Ensor Debbie Franke
Pollution Prevention: Waste Treatment	Norma Lewis	California Environmental Protection Agency	Greg Williams Tony Luan
Air Pollution Control Technologies	Ted Brna	Research Triangle Institute	Jack Farmer
Global Climate Change Technologies	Dave Kirchgessner	Southern Research Institute	Stephen Piccot
Advanced Monitoring Systems	Robert Fuerst	Battelle	Karen Riggs
Metal Plating/Finishing	Alva Daniels	Concurrent Technologies	Jim Voytko
Wet Weather Flow	Mary Stinson	NSF International	John Schenk
Source Water Protection	Ray Frederick	NSF International	Tom Stevens

consultants, and state regulators. For some pilots, the partner's facilities are utilized for technology testing, but testing is more commonly conducted at other testing facilities or demonstration sites.

1.2 Cost Evaluation Strategy

An ETV pilot's verification of the technical performance of a technology is likely to be fairly definitive. However, technology cost estimates are expected to incorporate more variability and uncertainty than technical performance evaluations, so it is useful to clearly differentiate the terms "cost verification" and "cost estimation."

Cost verification is a process that involves firsthand experience of the cost elements required by the ETV pilot during the verification project. Thus, the verification process actually measures individual cost items, such as labor (time of operation and labor rate), energy, and materials. Measuring various cost items may present different degrees of difficulty based on the length and comprehensiveness of the testing. If the objective is to test the technology in the ETV partner's facility, as some pilots do, then an effort to verify some cost items (such as installation, operating labor, and operating energy) could be made for some types of technologies. Firsthand verification of other cost items (such as maintenance) is more difficult if the verification process takes place over a short period. This is not to diminish the value of testing technologies in a partner's facility, because considerable information on the technical performance and certain cost items (such as operating labor and energy requirements) can be obtained from a simulated test in a partner's facility. However, direct verification of an item such as maintenance cost would require that a unit be installed in a user's facility for a period of one year or longer, or for the expected life of the technology.

Cost estimation, on the other hand, is a process that involves a combination of direct verification, engineering judgment by persons knowledgeable with the technology and its application, and previous experience with similar technologies by the ETV partners or vendors. Given the limitations of the ETV Program's verification process, directly verifying every cost item for all the technologies in all the pilots is not feasible. In fact, the number of cost items that were directly measured or verified has been limited in every other technology evaluation program. Ultimately, although the ETV Program directly verifies the technical performance of a technology under specified conditions, addressing costs probably will be a process of cost estimation rather than cost verification.

1.3 Summary of Cost Evaluation Options

After technical performance of a technology, cost is the most important factor that guides decision-making by potential users. Cost information is especially useful for technologies targeted toward small businesses, because such users are less likely to have the resources to evaluate technology costs. The ETV Program allows each pilot manager (ETV partners in collaboration with the U.S. EPA project officers) the flexibility to select a cost evaluation approach that best fits the resources and needs of the pilot, as well as the type of technology and its application. This document describes four different cost evaluation options that an ETV pilot manager could use:

- No cost evaluation (see Section 1.3.1)
- Itemization of costs (see Section 2)
- Estimation of capital investment and operation and maintenance (O&M) costs (see Section 3)
- Calculation of total annualized cost, simple payback period, or present value (see Section 4).

When using this document, ETV pilot managers decide either to not address costs, to address costs in a limited fashion, or to conduct a relatively comprehensive cost estimation and analysis. Stakeholder input also is taken into consideration when making this decision. Pilot managers wishing only to itemize relevant costs need not consider Sections 3 or 4 of this document. Also, each successive option mentioned in this list builds on the previous one, so that the fourth option (*Calculation of Total Annualized Cost, Simple Payback Period, or Present Value*) builds on and incorporates all the elements of the previous three on the list to provide a comprehensive cost evaluation. Appendices A through C contain illustrations of cost evaluation for three technologies.

These four options were first described in the earlier review document *Options for Collecting, Evaluating, and Reporting ETV Technology Costs* (Battelle, 1998). The review showed that at least one of the technologies tested so far under the ETV Program had been evaluated under the relatively comprehensive fourth option (*Calculation of Total Annualized Cost, Simple Payback Period, or Present Value*).

This document includes a standard cost reporting format that pilot managers can use in two ways: (1) In the planning stages of an ETV technology verification test, pilot managers could use this standard format as a checklist to ensure that all the required items for the cost evaluation will be tracked during testing. (2) Upon completion of the ETV technology verification test, the standard format could be used to ensure that all relevant items are presented and that potential users can use the reported costs to evaluate their own application or to compare competing technologies. Figure 1-1 shows how these options progressively lead to a comprehensive cost evaluation.

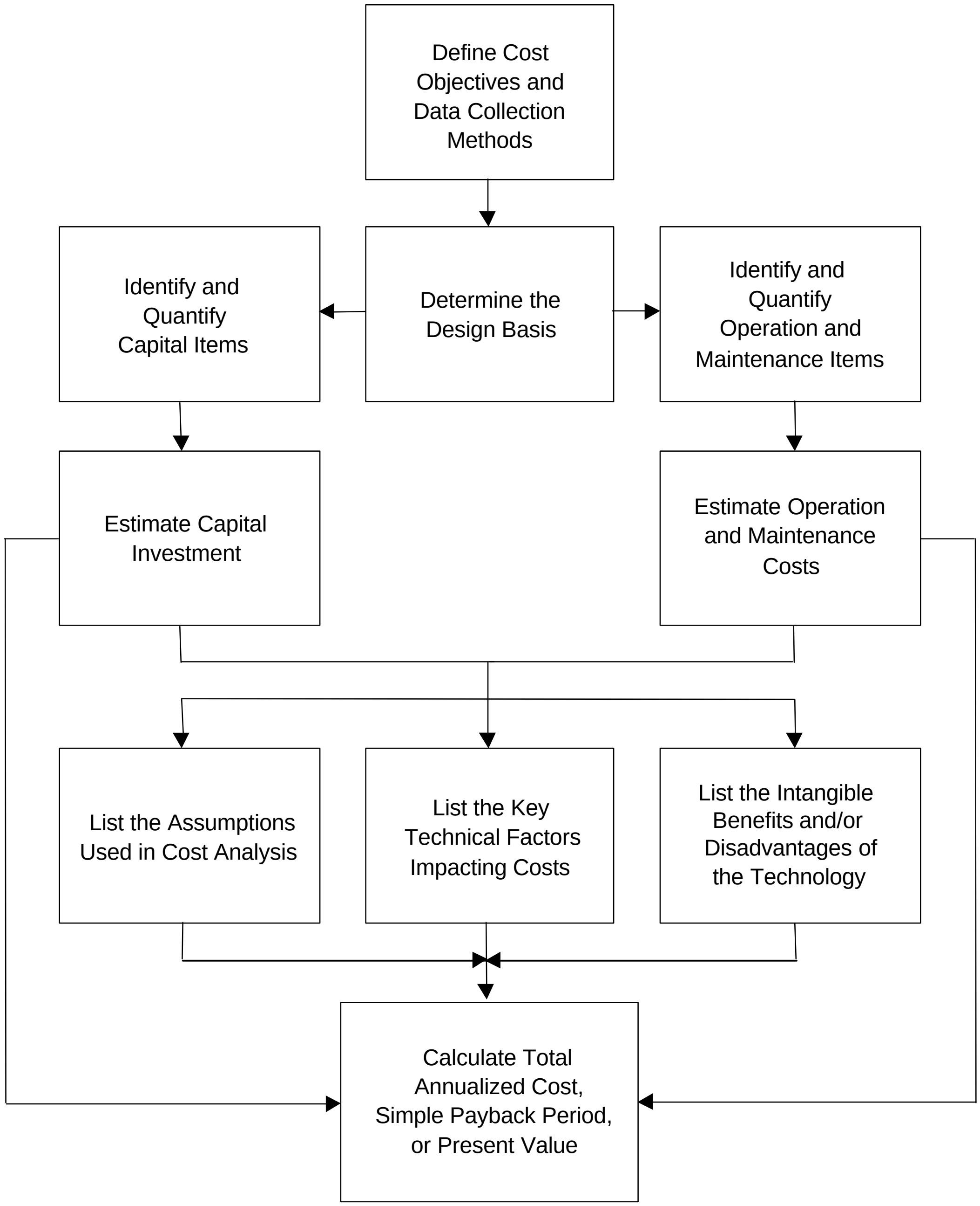

Figure 1-1. Summary of Cost Evaluation Methodology for ETV Technologies

ETV technologies are diverse enough that not all cost elements described in this document are appropriate for every technology. Therefore, cost tables and reporting formats are presented in this document as examples of elements to consider when performing a cost evaluation, and are not designed to be comprehensive for all pilots and/or technologies. In general, though, pilot managers should include in their evaluations as much relevant cost data as possible, as well as a description of the cost data not included in the evaluation.

1.3.1 No Cost Evaluation

One option that pilot managers may use is to not evaluate costs. Reasons why pilots may not address costs include difficulty or inability in obtaining the required cost items, lack of vendor or user interest in cost evaluation, or simply a wish to conserve limited financial resources for evaluating the technical performance of a technology. The rest of this document does not apply to pilots for which the *No Cost Evaluation* option is exercised.

1.3.2 *Itemization of Costs*

Section 2 of this document is suitable for pilot managers who want to perform a limited cost evaluation. In this option, the various cost items that may be applicable to the technology are identified and quantified, but monetary (dollar) values are not assigned. This option is suitable for pilot managers who may find it difficult to assign unit costs (or prices) for each cost item, either because the unit costs are likely to be highly variable from user to user in the affected industry or because the unit costs are not easily available.

1.3.3 *Estimation of Capital Investment and O&M Costs*

Section 3 describes the *Estimation of Capital Investment and O&M Costs* option, which builds on the *Itemization of Costs* option. In addition to identifying and quantifying the cost items associated with the ETV technology, unit costs (prices) are assigned for each item. Based on the quantity and unit cost of each item, the total cost of each item can be estimated.

1.3.4 *Calculation of Total Annualized Cost, Simple Payback Period, or Present Value*

Section 4 describes the *Calculation of Total Annualized Cost, Simple Payback Period, or Present Value* option, and is suitable for pilot managers who want to perform a more detailed cost evaluation of a technology. In this option, the total impact of an ETV technology on a potential user is assessed. This option also facilitates the comparison of the ETV technology with a baseline or competing technology. Assessing the total impact of a technology typically involves the calculation of a total annualized cost, simple payback period, or present value. This option builds on the *Estimation of Capital Investment and O&M Costs* approach, and is the most comprehensive of the cost evaluation options described in this document.

1.4 Quality Assurance/Quality Control

The quality assurance/quality control (QA/QC) activities associated with the data collection for cost evaluation are similar to those associated with data collection for technology verification purposes. If cost evaluation is desired, it should be identified as an objective in the project planning document. The data that need to be collected should be identified, along with the required source (if appropriate) and/or procedures used to collect the data. Depending on the needs of the project, any QA/QC requirements for the procedures used to collect the cost-related data also should be specified in the planning document.

The option used for cost evaluation also should be documented in the project report. The source of any data/information used in cost evaluation should be identified, and any assumptions used in estimating costs should be discussed. Also, any deviations from QA/QC requirements for measurements used to estimate costs should be discussed, along with the effect on cost evaluation results.

1.5 Reference

Battelle. 1998. *Options for Collecting, Evaluating, and Reporting ETV Technology Costs.* Prepared for U.S. EPA’s National Risk Management Research Laboratory, Cincinnati, OH. June.

2. Itemization of Costs

Costs are incurred when resources (capital) are invested and resources (inputs) are consumed to generate products (outputs). Depending on the industry, the product or output could be treated water effluent from a wastewater treatment plant, recycled solvent from a machine shop, a new environmentally friendly surface coating that replaces a conventional chromium coating, or the numerical result from the analysis of a soil sample. Inputs required to generate the product may include labor, materials, and/or energy. The *Itemization of Costs* option outlines a systematic way of identifying and quantifying these resources, without necessarily assigning monetary (dollar) amounts to them.

2.1 Identifying the Cost Evaluation Objective and Data Collection Methods

The cost evaluation objective functions to help a potential user decide whether to buy or not buy an ETV technology. The three types of cost evaluation objectives are:

- To estimate and compare the cost of the ETV technology to a "baseline" technology
- To estimate and compare the cost of the ETV technology to a "competing" technology
- To estimate the cost of an "add-on" ETV technology.

Often, a buy/no-buy decision on an ETV technology is based on a comparison of the cost of that technology with a baseline or competing technology. A *baseline* technology is one that is currently being applied by the user, and serves as the basis of comparison with the ETV technology. A *competing* technology is one that is available commercially and performs the same function as the ETV technology, but is not the baseline technology currently installed in the user's facility. The only case where a comparison between technologies may not be possible is when the ETV technology is an *add-on* (no replacement of a baseline technology is involved) and no competing technology is available to fulfill the technical objectives of the user. Before characterizing an ETV technology as an add-on, pilot managers should carefully consider whether or not a baseline technology or operation is being replaced. For example, a small coolant recycling unit may be "added on" to a metalworking plant. Although no existing equipment is being replaced, the new technology (on-site coolant recycling) is replacing a baseline technology (off-site coolant disposal). The net impact of adding the recycling unit can be determined only by comparing its cost to the cost of the baseline technology, and the resulting impact could be a net saving or a net cost.

It is important to identify the cost evaluation objective early in the ETV process so that the relevant cost items can be tracked during a verification test (see Section 2.6 for a discussion of relevant cost items). For many ETV technologies, this may involve tracking or estimating the costs of both ETV and baseline/competing technologies.

The data collection methods used to achieve the cost evaluation objective also should be identified in the planning stages and mentioned in the cost report. Many of the required cost data can be obtained by direct measurement during a verification test. However, it may not be possible to quantify all cost items through direct measurement. For example, the labor required to operate an ion exchange unit may be observed and measured during a one-week ETV test and extrapolated to one year of operation in a relatively straightforward fashion. On the other hand, the maintenance cost item may be difficult to measure directly during a one-week test. The quantities and costs of such items may have to be determined based on the engineering judgment of pilot managers or based on the experience of the vendor with previous applications.

2.2 Determining the Design Basis

The design basis refers to the performance specifications and equipment design requirements of the ETV technology. The performance specifications for a technology may include the desired product features, as well as features of the inputs, equipment, and operations involved. For example, a wastewater treatment plant may require that a technology be able to treat 1,000 gal/day of wastewater and meet an effluent target of no more than 1 mg/L of chromium. These requirements of product quantity and quality are part of the design basis for the technology. In addition, the plant also may require that the technology be able to handle wastewater with a pH of 3 and containing up to 2,000 mg/L of total dissolved solids. This limitation on the feed or input quality is also part of the design basis because it may impact the materials of construction used in the equipment and therefore the unit cost (price) of the equipment. It is important to identify the design basis at the beginning of the cost evaluation exercise, because once the design basis is established, the quantity and unit cost (price) of each individual item (e.g., equipment, labor, maintenance, etc.) of the technology application can be calibrated to this basis.

An important aspect of the design basis for cost evaluation is the *throughput* requirement of a technology. Throughput is the quantity of material processed through or produced by the ETV or baseline/competing technology in a specified period (usually, one year) of operation. Throughput can be measured in terms of the input (e.g., gallons of wastewater treated per year) or output (e.g., annual hot water usage with a new energy-efficient water heater) related to a technology. Although throughput can be measured for any period, the common practice is to determine throughput on an annual basis.

Note that the throughput generally is based on the expected requirement of a user of the ETV technology. Therefore, throughput may be different from the *capacity* of the equipment associated with the technology. Equipment capacity is the maximum throughput that is possible given the size of the equipment available or selected. The design throughput may be set at a value equal to or less than the capacity of the ETV technology equipment. If the design throughput is assigned to be equal to the capacity of the primary ETV technology equipment, it is essential that all associated equipment (i.e., pumps, piping, and valves) be designed to handle the same (or greater) capacity.

Because the actual throughput is likely to vary from user to user, the cost report should specify the design throughput used as the basis for developing estimates of both the quantities and costs of the individual cost items and the overall cost of the technology.

2.3 Identifying and Quantifying Capital Investment and O&M Costs

One distinction that is important to understand for cost evaluation is the difference between capital investment and O&M costs. *Capital investment* refers to the initial outlay of money required to acquire and install the technology in a user's facility. It includes all the costs incurred up to the point that the technology is ready to perform its desired function in the user's facility. Examples of capital items are purchased equipment, installation, and training associated with the ETV technology.

O&M costs are the recurring costs associated with the continued operation of the technology. Examples of O&M costs are operating labor, materials, and energy. Although O&M costs can be estimated for any time period, this document generally recommends estimating them on an annual basis.

Tables 2-1 and 2-2 show the main categories of capital items and O&M items, respectively, that are likely to be associated with an ETV technology. Not all the items will be applicable to all the technologies. These tables are designed to serve as checklists so a pilot manager can ensure that common capital and O&M items are not missed during the cost evaluation. Following subsections of this document describe these cost items in more detail.

2.3.1 Identifying and Quantifying Capital Items

Table 2-1 lists the common categories of capital items likely to be encountered for an ETV technology. Not all items will be applicable to all technologies. The quantity of each capital item is determined by the design basis of the user. For example, a user who wants to use a new ultrafiltration unit for one shift per day may need to train only one operator. On the other hand, another user who wants to use the unit continuously over three shifts per day may need to train three operators. Thus the quantity of training (one 8-hr day versus three 8-hr days of labor) and the associated training cost for the technology will be determined by the operating requirements of the user. Similarly, a user who has an annual throughput requirement of 80,000 gal of wastewater per year may buy an ultrafiltration unit with a rated capacity of 100,000 gal/yr (assuming that this is the next largest size of equipment available). Another user with a requirement of 180,000 gal/yr may opt for the next largest size of unit, rated at 200,000 gal/yr, or may buy two 100,000-gal/yr rated units. The design basis for the cost evaluation should be clearly stated in the ETV cost report.

Table 2-1. List of Capital Items

Site Preparation
- ❑ In-house (labor, materials)
- ❑ Demolition/clearing, grading/landscaping
- ❑ Old equipment/rubbish disposal
- ❑ Equipment rental
- ❑ Vendor/contractor services, including fees

Buildings and Land
- ❑ Equipment housing
- ❑ Plant expansion

Purchased Equipment
- ❑ Primary equipment
- ❑ Associated equipment (storage and materials handling equipment)
- ❑ Monitoring/control equipment
- ❑ Laboratory/analytical equipment
- ❑ Safety/protective equipment
- ❑ Freight/shipping and handling
- ❑ Licensing and/or warranty

Utility Connections/Systems
- ❑ Energy (electricity, fuel)
- ❑ Steam
- ❑ Process water and/or process air
- ❑ Sewer

Installation
- ❑ In-house (labor, materials)
- ❑ Piping, electrical, instrumentation, insulation, and painting
- ❑ Contractor/vendor/consultant services, including fees
- ❑ Construction supplies and support
- ❑ Equipment rental

Startup/Training
- ❑ In-house (labor, materials)
- ❑ Process adjustments
- ❑ Report writing
- ❑ Process/equipment testing, training
- ❑ Safety/environmental training
- ❑ Vendor/contractor services

Regulatory Issues/Permitting
- ❑ In-house (labor, materials)
- ❑ Permit fees
- ❑ Contractor/consultant services

Other
- ❑ Contingency
- ❑ Any other items

2.3.1.1 Site Preparation

This subcategory of cost items is used to account for expenses that may be incurred prior to the acquisition of an ETV technology. It is usually more relevant for large "system" technologies, and could include items such as in-house labor, demolition and clearing, grading and landscaping, equipment rental, and vendor/contractor service charges. In-house labor and materials may be required for activities, such as engineering (e.g., to design peripheral piping and instrumentation) or for building/plant modifications to house the equipment.

Table 2-2. List of O&M Items

Materials (purchase, delivery, storage)
- ❑ Raw materials
- ❑ Chemicals
- ❑ Catalysts
- ❑ Operating supplies

Utilities
- ❑ Water
- ❑ Sewage
- ❑ Energy (i.e., electricity, oil, gas, and/or steam)

Labor
- ❑ Operating
- ❑ Supervision
- ❑ Clerical

Maintenance
- ❑ Maintenance labor
- ❑ Materials
- ❑ Replacement parts (minor system components)

Waste Management (labor, materials)
- ❑ On-site handling
- ❑ Storage
- ❑ Treatment of waste
- ❑ Hauling
- ❑ Off-site treatment/disposal
- ❑ Generator fees
- ❑ Labeling
- ❑ Manifesting

Regulatory Compliance (labor, materials)
- ❑ Permitting
- ❑ Training
- ❑ Monitoring/inspections/testing
- ❑ Record-keeping/reporting

Other
- ❑ Any other items

2.3.1.2 Buildings and Land

This subcategory includes the space requirements and housing for the technology. It may include items such as building/plant modifications, facilities expansion, and construction of a special shelter to house the equipment.

2.3.1.3 Purchased Equipment

This subcategory is the core of most ETV cost evaluations. It is the purchase cost of the primary technology equipment and associated equipment (such as pumps, hoppers, etc.). This item may include equipment licensing and freight; monitoring/control equipment, laboratory equipment, and safety equipment also are included.

2.3.1.4 Utility Connections/Systems

This subcategory includes the cost of connecting the technology and associated equipment to providers of utilities such as electricity, water, and sewer.

2.3.1.5 Installation

Installation generally consists of labor and materials. Materials may consist of piping, structures, instrumentation, insulation, painting, and miscellaneous items. In-house labor may involve engineer, technician or skilled worker, and/or a supervisor. In addition to “in house” labor, contractor or vendor service charges may be applicable, as well as the contractor’s construction supplies and support. Equipment rental during installation is also included in this subcategory.

2.3.1.6 Startup/Training

Startup costs are extra operating costs incurred between the completion of installation and beginning of normal operations. It includes training, equipment tests, process adjustments, salaries and travel expenses of staff and consultants, report writing, and vendor fees.

2.3.1.7 Regulatory Issues/Permitting

This is the cost associated with obtaining the required permits to acquire and operate the technology. Permitting may include in-house labor, permit fees, and vendor and/or consultant charges.

2.3.1.8 Other

Any items that have not been included in Table 2-1 but are applicable should be listed in this subcategory. For example, “contingency" is a cost that may be added to an estimate to allow for any omissions and unforeseen costs; 10 to 15% is a typical range used to account for uncertainties.

2.3.2 Identifying and Quantifying O&M Items

Table 2-2 lists the common categories of O&M items likely to be encountered for an ETV technology. Not all items will be applicable to all technologies. The quantity of many O&M items generally is determined based on a user’s annual throughput requirement. For example, the quantities of labor, materials, and energy required to treat 180,000 gal/yr of wastewater are likely to be much higher compared to the quantities required to treat 80,000 gal/yr. The annual throughput assumed for the cost evaluation should be stated clearly in the ETV cost report.

2.3.2.1 Materials

This subcategory is used to account for materials that are consumed during the operation of the ETV technology. It includes items such as raw materials, chemicals, catalysts, and operating supplies.

2.3.2.2 Utilities

Utilities include water, sewage, and energy (i.e., electricity, oil, gas, and/or steam) required to operate the ETV technology and associated equipment.

2.3.2.3 Labor

This subcategory is used to account for the labor (salary or wages) required to operate the ETV technology and includes operating labor, supervisory labor, and clerical labor, as applicable.

2.3.2.4 Maintenance

This subcategory includes the labor and material costs of keeping the technology in good working condition. If maintenance labor is expected to be minimal, it may be difficult or unnecessary to distinguish it from operating labor. The materials could include items such as lubricants or filters.

2.3.2.5 Waste Management

Waste management includes the labor, materials, energy, or service charges/fees required for the handling, storage, and treatment (or off-site disposal) of any wastestream generated by the technology.

2.3.2.6 Regulatory Compliance

Regulatory compliance and environmental health and safety costs associated with the technology can include the labor and materials for permitting, training, monitoring, and record-keeping.

2.3.2.7 Other

Any items that are applicable to the ETV technology but are not included in Table 2-2 should be listed in this subcategory.

2.4 Listing the Assumptions Involved in a Cost Evaluation

Often, there are limitations in measuring actual quantities and costs of the inputs and outputs involved in a technology application. Working assumptions must be made based on the engineering judgement of the ETV pilot managers or on information provided by vendors. These assumptions should be mentioned in the ETV cost report so that potential users of the technology can assess the basis and limitations of the cost evaluation. Common assumptions may involve the following:

- Expected life of the technology: One technology feature that is often required for cost evaluation is the *life* of a technology. The life of a technology is important because it determines the total period over which the cost evaluation is applicable. For example, if a new catalytic oxidizer is expected to last for 7 years, then another catalytic oxidizer (or similar technology) will have to be purchased after 7 years, and a new cost cycle will begin. The life of a technology generally refers to the useful life of the primary equipment involved. For example, for a solvent recycling technology, the distillation still is the primary piece of equipment and may be expected to last for 10 years. Although some associated pieces of equipment (e.g., pumps) may wear out earlier, replacement of peripheral equipment may be handled as an O&M item (i.e., maintenance) as long as the primary equipment lasts. The expected life of the primary equipment generally can be determined on the basis of prior experience with similar equipment in the industry. The technology vendor also can provide some guidance on how long a particular piece of equipment may be expected to last.
- Cost items that are not relevant in the cost evaluation: Any assumptions regarding the exclusion of certain cost items from the evaluation should be mentioned. For example, some pilot managers may exclude the capital item "Buildings and Land" if it is not relevant to the cost evaluation.
- Cost items that are relevant but not included in the cost evaluation: In some cases, certain cost items may be relevant to the cost evaluation, but may not be obtainable for some reason. Such items should be mentioned in the list of assumptions. Some pilot managers have indicated that they may exclude portions of the capital investment category because vendors in their industry generally are reluctant to divulge the cost of capital items.
- Capital and O&M costs: Assumptions regarding the quantities of capital and O&M items assumed for the evaluation should be mentioned, especially when an extrapolation is involved in estimating annual quantities from shorter-duration ETV tests. When quantities are determined from sources other than direct measurements taken during the ETV test, the source of these data should be mentioned.
- Other: Any other assumptions that may affect the interpretation of the reported costs should be mentioned.

2.5 Listing the Technical Factors that Impact Costs

A single technology may be applicable under a variety of operating conditions, some of which may be different from the test conditions used during the ETV process. Some of this variability may be within the capacity of the technology to handle; some may not. Therefore, it is important not only to specify the conditions of the ETV test, but also to indicate which factors might significantly impact the overall cost of the technology. Examination of the design basis may provide an indication of the technical factors that impact costs.

For example, a catalytic oxidation unit may require considerably more energy (and higher O&M cost) to treat a feed airstream containing 30% humidity than a feed airstream with 10% humidity. Therefore, humidity should be listed as a factor impacting the cost of the technology. The volatile organic content of the airstream may affect the frequency with which the catalyst must be replaced or regenerated (a maintenance item). Therefore, the level of organics in the airstream should be listed as a factor affecting maintenance cost. Whether or not the effect of these factors is quantified depends on the level of cost evaluation desired by the individual pilot managers. Quantifying how much more energy and how much more maintenance (and the associated higher costs) may be required for the full range of these factors (humidity and level of organics) is a level of detail that would have to be a part of the technical verification of the technology, and would involve one or more of the following steps:

- Testing the technology under multiple test conditions (that is, with various input and operating characteristics).
- Using the informed engineering judgment of the pilot managers. In many cases, past experience with similar technologies can serve as a guide for identifying technical factors impacting costs. For example, even if ETV testing of a new energy-efficient residential water heater does not include testing at different inlet water temperatures, pilot managers may be able to predict that the energy requirement (and therefore the O&M cost) of the water heater is likely to be higher when the input water is cooler and lower when the input water is warmer. In this example, the inlet water temperature (which depends on the location of the user) is a technical factor impacting annual energy cost.

- Acquiring data from the technology vendor regarding previous applications of the ETV or similar technologies.

Although quantifying these impacts may be difficult, pilot managers at a minimum should identify and list the factors likely to significantly affect any of the relevant cost items. If such impacts can be quantified, pilot managers could provide a *range* of quantities instead of a single number. For example, instead of reporting the energy requirement of an energy-efficient water heater as 22,000 kBTU/yr, pilot managers could report it as 20,000-24,000 kBTU/yr, to cover the expected range of energy consumption based on average inlet water temperatures in different geographical regions, or on water usage, or on other variables.

2.6 Listing the Intangible Benefits and/or Disadvantages of a Technology

Intangible benefits/disadvantages of an ETV technology are those features that cannot be quantified by the monetary cost evaluation, but nevertheless are relevant to the buyer's decision. Although they are difficult (or impossible) to quantify, the intangible benefits and/or disadvantages of a technology can outweigh the results of the tangible cost evaluation, thus affecting the buy/no-buy decision of potential users.

For example, potential users may find it beneficial to implement the ETV technology even if it costs more than the baseline technology. Table 2-3 is a checklist of possible ETV technology benefits and disadvantages. Given the wide variety of technologies involved in the ETV Program, this is by no means a comprehensive list; however, it may be used as a guide to identify and list relevant benefits/disadvantages.

Table 2-3. List of Intangible Benefits/Disadvantages

Benefits

- ❑ Energy conservation
- ❑ Water conservation
- ❑ Reduced ozone depletion
- ❑ Reduced future liability
- ❑ Reduced global warming
- ❑ Reduced Toxics Release Inventory
- ❑ Promotion of positive public relations
- ❑ Increased plant safety
- ❑ Increased ease of use
- ❑ Superior product or unique service provided
- ❑ Other (state here) ____________________

Disadvantages

- ❑ Higher maintenance requirements
- ❑ Increased energy consumption
- ❑ Other (state here) ____________________

2.7 Preparing a Cost Evaluation Report

The recommended reporting format for the *Itemization of Costs* option includes the following elements:

- Cost evaluation objective and data collection methods
- Design basis
- Table of capital items
  - Include the description and quantity of each capital item
- Table of O&M items
  - Include the description and quantity of each O&M item
- List of assumptions
- List of technical factors that impact costs
- List of intangible benefits/disadvantages.

3. Estimation of Capital Investment and O&M Costs

In this section, cost evaluation is taken a step further than the process described in Section 2 for itemizing costs. To estimate the monetary (dollar) costs of the capital and O&M items described in Section 2, unit costs (or prices) of the various items need to be determined and multiplied by the quantities of each item. This process of monetizing relevant cost items allows pilot managers to combine costs and thereby to obtain a more comprehensive perspective of the technology. The impact of various cost items (e.g., labor and materials) can be combined only when they are quantified with a common measure, and monetizing the cost items provides this common measure. For example, the electricity consumption (measured in kWh) and the labor requirement (measured in hours) of a technology can be combined only when they are converted to dollar amounts.

3.1 Estimating Capital Investment

Section 2.3.1 describes the various capital items that may be encountered when evaluating the cost of an ETV technology. In the *Itemization of Costs* option described in Section 2, the quantity of each capital item required to fulfill the design basis of the user is identified and listed. To estimate the dollar value of a capital investment, the unit cost (or price) of each capital item needs to be obtained and listed as shown in Table 3-1. The quantity of each capital item is multiplied by its unit cost to obtain the dollar value of each item. All of the items then can be added to obtain the total capital investment.

3.2 Estimating O&M Costs

Section 2.3.2 describes the various O&M cost items likely to be encountered by ETV pilot managers. The unit costs (prices) of these items are required in order to convert the quantities of these items to dollar costs. As shown in Table 3-2, the cost of each O&M item is estimated by multiplying the quantity of an item with its unit cost.

Table 3-1. Capital Investment for a Hypothetical Water Treatment Unit

	Water Treatment Unit		
Item	Quantity*	Unit Cost	Cost
Buildings and Land			
Prefabricated steel structure	1	$5,000	$5,000
Purchased Equipment			
Water treatment package plant	1	$21,625	$21,625
Upgrades to standard package plant			
Chemical feed for well supply	1	$1,000	$1,000
Air compressor	1	$1,000	$1,000
Chlorine monitor	1	$3,225	$3,225
Flowmeter package	1	$2,600	$2,600
Telemetry system and software	1	$2,220	$2,220
Underground waste storage system	1	$6,845	$6,845
Freight	1	$900	$900
Installation			
Technician	100 hr	$35/hr	$3,500
Engineer	100 hr	$60/hr	$6,000
Startup/Training			
Vendor startup services	1	$4,000	$4,000
Total Capital Investment			**$57,915**

* For the design basis described in the illustrative example in Appendix A.

3.3 Additional Considerations in Estimating Capital Investment and O&M Costs

A few issues may be important to note while estimating capital investment and O&M costs. One issue to note is the purchase price of the primary ETV technology equipment (for example the filtration unit for an ultrafiltration technology), because this price is often a significant part of the capital investment and is a unit cost that needs to be obtained from the vendor. However, when large customized pieces of equipment are involved, vendors sometimes are reluctant to divulge their prices. In this case, pilot managers may have no choice but to exclude the cost of the primary equipment from the cost evaluation.

Table 3-2. Annual O&M Costs for a Hypothetical Nickel Recovery System

Item	Electrodialysis System Annual Quantity*	Unit Cost	Annual Cost
Materials			
Makeup water	15,000 gal	$4.19/1,000 gal	$63
Chemicals, $NiSO_4$ used	180,000 lb	$1/lb	$180,000
Chemicals, $NiSO_4$ recycled	–171,000 lb	$1/lb	–$171,000
Utilities			
Steam	4.9×10^8 BTU	$6/10^6 BTU	$2,940
Electricity	78,600 kWh	$0.118/kWh	$9,275
Maintenance			
Service contract	4 visits	$3,000/visit	$12,000
Carbon change	6 events	$1,020/event	$6,120
Evaporator cleaning	12 events	$120/event	$1,440
Miscellaneous upkeep	1	$1,000	$1,000
Total Annual O&M Cost			**$41,838**

* For the design basis described in the illustrative example in Appendix B.

On the other hand, pilot managers generally are not dependent on technology vendors for the costs of other capital items, such as site preparation and installation. The quantity and unit costs of these capital items can either be determined during the technology verification part of the ETV test or estimated from other sources. For example, pilot managers may determine during the ETV test that installation of an ultrafiltration unit requires 40 hours of labor at $50/hour and 30 ft of pipe at $2/ft. The installation cost of the ultrafiltration unit can be calculated from these data. Other sources for estimating the costs of these capital items includes the engineering judgement of pilot managers or vendors (based on experience with other similar equipment) or published references that list costs or cost factors for these items. These references are described in Appendix D. Cost factors are rule-of-thumb cost estimates for certain items based on the cost of other associated items. For example, based on the information compiled in such references, pilot managers may estimate that "installation" cost is 20% of the "purchased equipment" cost of a technology. If these alternative estimation sources are used, then they should be identified in the list of assumptions.

Another issue that needs to be noted is that the unit costs (prices) of various capital and O&M items are likely to vary from user to user and from technology to technology. To handle this variability, it is important to clearly state the unit cost numbers in the ETV cost evaluation report. A stated list of unit cost numbers (as shown in Table 3-1) permits individual users to see how their own unit costs differ from the unit costs applied in the ETV cost evaluation. Users can thereby assess the impact of these differences on the overall cost of a technology. Representative unit costs of several capital items associated with environmental technologies can be obtained from cost references such as the *Environmental Remediation Cost Data—Unit Price* handbook (R.S. Means Company, Inc., and Talisman Partners, Ltd., 2001). This handbook provides representative unit costs for a variety of associated equipment, such as pumps, piping, and valves, along with the cost of their installation.

Another issue relates to the procedure for handling the potential income from use of certain pollution prevention technologies. Some pollution prevention or recycling technologies can generate income for the user from the ability to market or reuse a recycled product. In this document, the recommended way of dealing with this income is to show it as an O&M cost with a negative sign. This negative number serves to reduce the annual O&M cost of the ETV technology. For the nickel recovery system example presented in Table 3-2, 171,000 lb of nickel sulfate are recovered and reused in the electroplating operation. The value of this recycled nickel (as nickel sulfate) is entered in the table as a negative number. The recycled nickel serves to reduce the amount of nickel sulfate that the plant needs to purchase annually. The value of the recycled nickel is therefore credited toward the annual O&M cost of the electrodialysis technology. A more detailed cost analysis that compares the annual operating cost of the nickel recovery system and the baseline operation is presented as an example in Appendix B.

Several of the cost items in Tables 3-1 and 3-2 involve in-house labor, which is an item that may be represented in terms of the salaries or wages paid to personnel conducting the work. If any other associated costs are included in the in-house labor item, they should be stated in the list of assumptions (see Section 2.4). Costs associated with labor could include fringe benefits (e.g., vacation or sick leave) and other overhead items, and these costs are sometimes factored in the labor rate. Because many of these associated costs are likely to vary from user to user, it may be simpler to estimate labor costs in terms of just salaries or wages.

3.4 Listing the Assumptions

Any assumptions made regarding the unit costs (prices) for the capital and O&M items should be mentioned, so that users can compare them with their own unit costs. For further details on listing assumptions, see Section 2.4.

3.5 Listing the Technical Factors that Impact Costs

See the discussion in Section 2.5.

3.6 Listing the Intangible Benefits/ Disadvantages of a Technology

See the discussion in Section 2.6.

3.7 Preparing a Cost Evaluation Report

The recommended reporting format for the *Estimation of Capital Investment and O&M Costs* option includes the following elements:

- Cost evaluation objective and data collection methods
- Design basis
- Table of capital investment
  - Include the quantity and unit cost (price) of each capital item
- Table of O&M costs
  - Include the quantity and unit cost (price) of each O&M item
- List of assumptions
- List of technical factors that impact costs
- List of intangible benefits/disadvantages.

3.8 Reference

R.S. Means Company, Inc., and Talisman Partners, Ltd. 2001. *Environmental Remediation Cost Data—Unit Price,* 7th ed.

4. Calculation of Total Annualized Cost, Simple Payback Period, or Present Value

Sections 2 and 3 describe how to quantify capital and O&M items and how to estimate the costs of these items. A cost analysis serves to assess the total impact of the ETV technology on a potential user and also facilitates the comparison of the ETV technology with a baseline or competing technology. The total user impact of a technology can be assessed by combining capital investment and O&M costs into an overall technology cost involving one of the following measures:

- Total annualized cost
- Simple payback period
- Present value (PV) of a technology.

4.1 Calculating the Total Annualized Cost

Calculating the total annualized cost of a technology involves combining the capital investment and annual O&M cost. Because O&M costs are measured on an annual basis ($/year), the capital investment must be annualized in order to combine these costs. In the following equation, the annual O&M costs are added to an annualized capital investment term to obtain a total annualized cost for the technology:

$$\begin{bmatrix}\text{Total}\\\text{annualized}\\\text{cost}\end{bmatrix} = \begin{bmatrix}\text{Annualized}\\\text{capital}\\\text{investment}\end{bmatrix} + \begin{bmatrix}\text{Annual}\\\text{O\&M}\\\text{cost}\end{bmatrix} \quad (4\text{-}1)$$

The annualized capital investment term can be interpreted as a fixed annual payment that a user would have to make every year over the life of the technology. The annualized capital investment can be estimated using the following equation, which shows how the capital investment can be annualized based on a discount rate, r:

$$\begin{bmatrix}\text{Annualized}\\\text{capital}\\\text{investment}\end{bmatrix} = \frac{\text{Capital investment}}{\sum_{t=1}^{t=n} \frac{1}{(1+r)^t}} \quad (4\text{-}2)$$

The discount rate accounts for the return (or interest) that the money assigned for capital investment would earn if the capital items were paid for over several years, at the end of each year (time, t = 1, 2, 3, …, n). The appropriate discount rate will vary from industry to industry and pilot managers need to select a rate accordingly. The values of the denominator of Equation 4-2 have been documented for various values of r and n; these denominator values are presented in Appendix E, and can be used in Equation 4-2 to facilitate the calculation.

Appendix A provides an example calculation of total annualized cost for a dual-stage filtration system installed in a drinking water plant.

Total annualized cost also can be represented on the basis of each unit of throughput to obtain a unit annualized cost for a technology, as shown in Appendix F. Unit annualized cost numbers (e.g., $0.25 per gallon of water treated) obtained from total annualized cost estimates can be misleading because the unit cost of a technology is dependent on the design basis, particularly the annual throughput. Therefore, different users may experience different unit costs for the same technology, depending on their throughputs. However, unit costs often are used in some industries for comparing technologies.

4.2 Calculating the Simple Payback Period

The simple payback period is defined as the time period over which the net O&M income and/or savings become equal to the initial capital investment. Calculating the simple payback period for a technology is a method of assessing the overall cost impact of a technology by estimating the time it would take to recover the initial capital investment. The simple payback period method is based on the assumption that implementing the ETV technology will generate measurable annual O&M savings or income for the user. Net O&M income and/or savings from implementing the new technology can arise in two possible ways. First, the ETV technology could generate a product or byproduct that has a marketable value greater than the O&M cost for operating the technology. This could happen, for example, when a solvent recycling technology generates recycled solvent that can be sold (or reused) to generate significant income. Second, net O&M savings could occur when the O&M costs of the ETV technology are lower than the O&M costs of the baseline technology that it replaces. This could happen, for example, when a conventional water heater is replaced with an energy-efficient heater. The reduction in energy usage (an O&M item) would lead to a reduction in O&M costs; the resulting savings could offset the initial capital investment over time.

Equation 4-3 can be used to calculate simple payback period when the annual O&M savings are constant every year, which is often the case. The discount rate or the rate of return that is forgone on the capital investment is ignored in this simplified equation. Therefore, this equation is useful as a quick analytical tool for assessing the attractiveness of the technology. The denominator in Equation 4-3 is the net annual O&M after-tax savings, which can be calculated as shown in Equation 4-4. In this equation, net annual O&M savings is the difference between the annual O&M cost of the baseline/competing technology and the annual O&M cost of the ETV technology. To estimate the net savings on an after-tax basis, Equation 4-4 includes a factor based on the corporate income tax rate.

$$\begin{bmatrix}\text{Simple}\\ \text{payback}\\ \text{period}\\ \text{(years)}\end{bmatrix} = \frac{\begin{bmatrix}\text{Capital investment}\\ \text{for the ETV technology}\end{bmatrix}}{\begin{bmatrix}\text{Net annual O\&M}\\ \text{after-tax savings}\end{bmatrix}} \qquad (4\text{-}3)$$

Section 4.3 offers a method for calculating discounted payback period that accounts for the rate of return, as well as for cases when annual O&M costs vary from year to year. Appendix B offers an example calculation of simple payback period for a nickel recovery system for treating wastewater from a metal-plating operation.

$$\begin{bmatrix}\text{Net annual}\\ \text{O\&M}\\ \text{after-tax}\\ \text{savings}\end{bmatrix} = \begin{bmatrix}\text{Net annual}\\ \text{O\&M}\\ \text{savings}\end{bmatrix} \times \left[1 - \begin{Bmatrix}\text{Corporate}\\ \text{income}\\ \text{tax rate}\end{Bmatrix}\right] \qquad (4\text{-}4)$$

4.3 Calculating the Present Value of a Technology

The present value (or life cycle cost) of an ETV technology is defined as the value of all the costs incurred over the useful life of a technology discounted to the base time (time of acquisition of the technology). These costs include the initial capital investment, which generally is incurred as soon as the new technology is acquired, and annual O&M costs and/or savings, which occur over several years as the technology is used. In order to combine present and future cash flows, any estimation of total lifetime cost must incorporate the effects of time on these cash flows. The most common way to account for the effects of time is by calculating the PV of all costs (capital investment and O&M costs) incurred in the present and future.

In general, a technology user usually needs enough cash today to pay for the full amount of the capital investment. However, O&M cash flows that are scheduled to occur in the future tend to free up money for productive uses in the present. Using PV calculations, a user can determine how much money he/she could set aside (i.e., invest in productive uses) today in order to grow the money to an amount equal to these future O&M costs. For example, if a user wanted to invest enough money today to pay for O&M costs that are likely to occur over the next three years, he/she would use the PV equations described in the following subsections to calculate PV where time t = 3.

Generally, cash flows for an ETV technology are measured on an annual basis. The PV of a series of cash flows (CF_t) that may occur at different points in time (t) over a total time period (n) may be estimated using the following general equation:

$$\text{PV of cash flows} = \sum_{t=0}^{t=n} \frac{CF_t}{(1+r)^t} \qquad (4\text{-}5)$$

Time t = 0 represents the present or the time when the technology is first acquired; also, all cash flows that occur in a given year are assumed to occur at the end of the year, so fractional values of t are avoided.

If all cash flows are estimated in real dollars or constant dollars, then r is the real discount rate, a rate which discounts future real cash flows to the present. The real discount rate reflects the real earning power of money over time. This approach is easier for cost analysis because it is easier to estimate costs in constant dollars, and it automatically accounts for any inflation that may occur. Therefore, the real discount rate (r) is based on the user's expectation of the real return on his/her prudent investment, and this expectation may vary from industry to industry. It is important to mention clearly the real discount rate assumed in the ETV cost analysis.

$$\begin{bmatrix}\text{PV of}\\ \text{cash}\\ \text{flows}\end{bmatrix} = CF_0 + \frac{CF_1}{(1+r)^1} + \frac{CF_2}{(1+r)^2} + \ldots + \frac{CF_n}{(1+r)^n} \qquad (4\text{-}6)$$

where, for many technologies:

n = life of the equipment in years

CF_0 = capital investment

$CF_1, CF_2, \ldots CF_n$ = annual O&M costs in Years 1, 2, …, n.

For most ETV technologies, the capital investment will result in a cash outflow at time t = 0, and all future cash flows will result from O&M costs. Also for many ETV technologies, the annual O&M costs are likely to be the same every year. In this case, Equation 4-5 can be simplified as:

$$PV = \left[\begin{matrix}\text{Capital}\\ \text{investment}\end{matrix}\right] + \left[(\text{O \& M cost}) \times \left\{\sum_{t=1}^{n} \frac{1}{(1+r)^t}\right\}\right] \quad (4\text{-}7)$$

The values of the factors in braces { } have been documented for different values of r and n, and are listed in Appendix E. Equation 4-7 is a simplified way of calculating the PV of an ETV technology when the O&M costs are the same every year. However, if O&M costs are likely to vary from year to year, Equation 4-5 or 4-6 must be used. Equation 4-5 or 4-6 also can be represented in a spreadsheet for ease of calculation. Appendix C provides an example spreadsheet calculation of PV for an energy-efficient water heater and a competing technology.

A PV spreadsheet also allows an easier determination of the discounted payback period. Section 4.2 describes a simple payback period calculation that does not take into account the time value of money. A discounted payback period is defined as the time (in number of years) that it takes to recover the initial capital investment in the ETV technology, given a discount rate (r). In a PV spreadsheet, the discounted payback period is the year in which the cumulative PV of the ETV technology becomes equal to the cumulative PV of the baseline technology. An example of a discounted payback period estimation based on a PV spreadsheet is shown in Appendix C.

An important consideration when comparing the ETV technology with a baseline technology is that the capital investment in the baseline technology should be excluded from the cost evaluation. The capital investment in the baseline technology has already occurred in the past and is irrelevant to today's decision on whether or not to buy the ETV technology. Therefore, only the ongoing O&M costs of the baseline technology need to be considered, along with the capital investment and O&M costs of the ETV technology. On the other hand, both capital investment and O&M costs need to be considered when the comparison involves two competing technologies, because both the ETV technology and the competing technology require a fresh capital investment.

If the baseline technology equipment has significant salvage value, it may be included in the PV of the ETV technology as a cash inflow or income at time t = 0, which will serve to offset the capital investment required for the ETV technology. For simplicity, the salvage value of capital equipment can be excluded from present value calculations. The salvage value is difficult to estimate and is often less than the cost of recovering the equipment. If salvage value is significant, but not included, then it should be explained in the list of assumptions that the analysis does not include salvage value.

An advantage of the PV analysis is that technologies with different lifetimes can be compared. In this case, the PV should be calculated for a period equal to the lowest common multiple of the two lifetimes. For example, if Technology A has a life of 5 years and Technology B has a life of 3 years, a second capital investment will be required in Technology B at the end of Year 3. In real dollars, the second capital investment may be the same or lower than the first capital investment; some capital items, such as training and permitting, may not have to be reincurred. Equation 4-6 can be used to determine the PV cost of the technologies. In this case, the PV analysis should be done for each technology over a period of 15 years. For Technology B, the cash flow in Years 3, 6, 9, and 12 (CF_3, CF_6, CF_9, and CF_{12}) will include, in addition to the O&M cost for the full 15 years, the capital investment required to replace the primary equipment. A spreadsheet may be used to facilitate calculation of PV when the time period of the analysis is very large.

4.4 Comparing Two Technologies

Often, the cost of an ETV technology will be evaluated against the cost of a baseline technology or a competing technology. The total annualized cost, simple payback period, or PV may be calculated separately (using an equivalent design basis) for each of the technologies involved in the comparison. The technology with the lower total annualized cost, simple payback period, or PV may be expected to provide a better return on investment or generate lower overall costs.

The intangible benefits and/or disadvantages of the ETV technology should also be considered a part of the technology comparison. Even if an ETV technology has a higher overall cost, the intangible benefits of using an environmentally friendly technology may be attractive enough to affect the decision of a potential user.

4.5 Preparing a Cost Evaluation Report

The recommended reporting format for the *Calculation of Total Anualized Cost, Simple Payback Period, or Present Value* approach includes the following elements:

- Cost evaluation objectives and data collection methods
- Design basis
- Table of capital investment
  - Include the quantity and unit cost (price) of each capital item
- Table of O&M costs
  - Include the quantity and unit cost (price) of each O&M item
- List of assumptions
  - Expected life of the technology used for the cost evaluation
  - The discount rate used
  - Other assumptions
- List of technical factors that impact costs
- List of intangible benefits/disadvantages
- Total annualized cost, simple payback period, or PV.

Appendix A

Illustration of Capital Investment/O&M Cost Estimation and Total Annualized Cost Analysis of a Dual-Stage Filtration System in a Drinking Water Plant

This example cost evaluation incorporates the eight bulleted elements listed in Section 4.5 and calculates the total annualized cost of a hypothetical dual-stage pressure filtration (DSF) unit.

The technology used in this illustration is a prepackaged filtration technology for a community drinking water system designed to reduce turbidity and iron to new regulatory target levels in the treated water. The technology consists of a prepackaged DSF unit.

A.1 Defining the Cost Evaluation Objective and Data Collection Methods

The first element is to define the objective of the cost evaluation and to describe the methods used to accomplish the objectives. The objective of the evaluation was to estimate the cost of the DSF application for a typical community drinking water treatment plant and compare it to a competing technology. The competing technology is a conventional coagulation/filtration unit. In this example, the cost analysis includes an estimation of the total annualized cost of the DSF unit.

For the verification test, the DSF unit was installed at an existing small community water treatment site. The test site was selected because of the nature of its water quality, high turbidity, and elevated iron levels. Performance and cost data were gathered for one year. Capital investment and O&M costs were tracked during the test; however, site-specific factors can contribute to wide variations in the costs a system incurs for treatment.

The cost of the competing (conventional) technology was estimated by a combination of reported costs from existing plants and engineering judgment.

A.2 Describing the Design Basis

The next element is to describe the design basis of the technology. The DSF unit is designed to operate automatically with off-site monitoring through a telemetry system by the operator. Daily turbidity levels in groundwater averaged 5 to 30 nephelometric turbidity units (NTU). The system was required to achieve 0.5 NTU in 95% of the samples collected, reduce iron to improve taste and odor, and supply water to 35 connections and 100 persons. The system operated an average of 300 hrs per month, the service flowrate averaged 10 gpm, and 2.16 million gallons of water were produced during one year. The design basis is summarized in Table A-1.

Table A-1. Design Basis for the DSF Unit

DSF Unit
Service flow, gpm: 10
Annual throughput (drinking water produced), gal/yr: 2.16 million
Number of connections: 35
Average turbidity levels: 5 to 30 NTU
Turbidity removal: 95% 0.5 NTU

A.3 Estimating Capital Investment

The next element is to determine the capital investment for the DSF unit. Table 2-1 in Section 2 of this document provides a checklist of capital items. For this example, the relevant capital items that apply include the cost of buildings and land, purchased equipment, installation, and startup/training. Regulatory/permitting and contingency items were not included in this estimate because no permits were involved for the demonstration. Also, because actual (and not budgeted) installation costs were available, no contingency was included. The source of the cost data is provided so that the user can verify the information or compare the data with other cost estimates. For this illustration, costs incurred during the purchase, installation, and startup of the technology were tracked during the verification test. The vendor provided the purchase price of the prepackaged equipment. Items such as upgrades that were not a part of the standard package are included in the purchase price, whereas items that were added for the purpose of demonstration (such as extra monitoring equipment) are excluded. Table A-2 summarizes the capital investment required for the DSF unit.

Table A-2. Capital Investment for the DSF Unit

Item	DSF Unit Quantity*	DSF Unit Unit Cost	DSF Unit Cost
Buildings and Land			
Prefabricated steel structure	1	$5,000	$5,000
Purchased Equipment			
DSF Package	1	$21,625	$21,625
Upgrades to standard package plant			
Chemical feed for well supply	1	$1,000	$1,000
Air compressor	1	$1,000	$1,000
Chlorine monitor	1	$3,225	$3,225
Flowmeter package	1	$2,600	$2,600
Telemetry system and software	1	$2,220	$2,220
Underground waste storage system	1	$6,845	$6,845
Freight	1	$900	$900
Installation			
Technician	100 hr	$35/hr	$3,500
Engineer	100 hr	$60/hr	$6,000
Startup/Training			
Vendor startup services	1	$4,000	$4,000
Total Capital Investment			**$57,915**

* Refer to Table A-1 for the design basis.

The capital investment required for a similar-sized conventional coagulation/filtration unit was reported by other drinking water plants to be $75,680 (adjusted based on engineering judgment).

A.4 Estimating O&M Costs

The next element is to determine the relevant O&M costs. For this illustration, Table 2-2 in Section 2 of this document was used as a guide; O&M items include materials (chemicals), utilities (energy and telephone), labor (operating, maintenance), and regulatory compliance (monitoring), all of which are considered relevant. The unit cost and amount required for each component were estimated based upon the observations made during the test and discussions with the vendor. Some minor system components associated with the DSF unit will require replacement approximately every 5 years. The periodic replacement cost (maintenance cost item) was determined as an annual O&M cost by dividing the replacement cost by the expected life, as shown in Table A-3. The vendor provided information regarding the expected life of the minor system components. Annual O&M costs are summarized in Table A-4.

Table A-3. Estimation of Annual Replacement Costs for the DSF Unit

Item	Annual Cost
Anthracite	$300
Feed pumps	$2,000
Raw water pump	$2,000
Backwash pump	$2,200
Turbidimeter	$4,500
Chlorine monitor	$3,000
Total Replacement Cost	$14,000
Expected Life	5 years
Annual Replacement Cost*	**$2,800/year**

* Part of maintenance cost item.

Table A-4. Annual O&M Costs for the DSF Unit

Item	DSF Unit Annual Quantity*	DSF Unit Unit Cost	DSF Unit Annual Cost
Materials			
Coagulant	60 gal	$9/gal	$540
Chlorine	48 gal	$1.6/gal	$76.8
Utilities			
Electricity	12 months	$120/month	$1,440
Telephone	12 months	$80/month	$960
Labor			
Operating labor (includes maintenance)	96 hrs	$35/hr	$3,360
Regulatory Compliance			
Monthly microbiological sampling	12 samples	$20/sample	$240
Quarterly tests for iron	4 samples	$30/sample	$120
Maintenance			
Labor (included in operating labor as itemized above)	–	–	–
Materials	Misc.	$400	$400
Replacement of filter media and equipment (annualized)	1	$2,800	$2,800
Total Annual O&M Cost			**$9,937**

* Refer to Table A-1 for the design basis.

The annual O&M cost of the similarly sized conventional technology was estimated to be $18,900. This estimate was based on the costs reported by other plants and the engineering judgment of the cost engineer.

A.5 Listing the Assumptions

The next element is very important because it allows users to verify and compare the cost data with other cost estimates. The following key assumptions that impact the cost analysis, such as operating parameters, also should be included:

- The expected life of the DSF unit is 20 years. The time period of the cost analysis is 20 years. The same assumptions were made for the conventional technology.
- Costs are in real (constant 2001) dollars.
- The real discount rate used is 6%.
- Cash flows occur at end of the year.
- The maintenance cost is based on the vendor's recommendation on replacement of filter media and associate pumps and meters every 5 years. The replacement cost of the filter media and associated equipment is $14,000. The annual replacement cost ($2,800) was calculated by dividing the replacement cost by the expected life.
- Extra capital investment and O&M items, such as labor, were required for the verification testing. The testing-related effort and costs have been deducted to reflect the cost of routine operation.
- Costs associated with regulatory/permitting activities and contingency are not included in the estimate.

A.6 Listing Key Technical Factors that Impact Costs

Another important element is to identify key technical factors that impact costs. For the DSF unit, the technical factors affecting cost are:

- If the feed water contains high levels of colloidal solids, filters may have to be replaced more frequently, thus increasing maintenance cost. A filter aid may be necessary.
- High levels of total organic carbon in the feed water may increase chlorine demand and increase O&M costs.

A.7 Listing the Intangible Benefits/Disadvantages

The intangible benefits and disadvantages of the technology should be described, using Table 2-3 of Section 2 as a guideline. Good public relations achieved by the plant due to the improved drinking water supply was the main intangible benefit of the DSF system.

A.8 Calculating Total Annualized Cost

To calculate the total annualized cost of the DSF system, the following equations were used:

$$\begin{bmatrix}\text{Total}\\ \text{annualized}\\ \text{cost}\end{bmatrix} = \begin{bmatrix}\text{Annualized}\\ \text{capital}\\ \text{investment}\end{bmatrix} + \begin{bmatrix}\text{Annual}\\ \text{O\&M}\\ \text{cost}\end{bmatrix} \qquad \text{(A-1)}$$

$$\begin{bmatrix}\text{Annualized}\\ \text{capital}\\ \text{investment}\end{bmatrix} = \frac{\text{Capital investment}}{\sum_{t=1}^{t=n} \frac{1}{(1+r)^t}} \qquad \text{(A-2)}$$

$$= \frac{57{,}915}{11.46992} \qquad \text{(A-3)}$$

$$= \$5{,}049 \qquad \text{(A-4)}$$

Total annualized cost = $5,049 + $9,937 = $14,986.

Here, r is the real discount rate (assumed as 6% for this cost evaluation). The estimated life (n) of the technology is 20 years. For r = 6% and n = 20, the denominator in Equation A-2 is 11.46992 (from Appendix E). The capital investment ($57,915) and annual O&M costs ($9,937) are obtained from Tables A-2 and A-4, respectively. The total annualized cost based on Equation A-1 is $14,986/year.

In the same way, based on a capital investment of $75,680 and an annual O&M cost of $18,900, the total annualized cost of the conventional coagulation/filtration technology was calculated as $25,498/year. A discount rate of 6% and a life of 20 years was assumed for the conventional unit.

The total annualized cost of the DSF unit ($14,986/year) is lower than the total annualized cost of the conventional unit ($25,498/year). The DSF unit is therefore more economical.

Appendix B

Illustration of Capital Investment/O&M Cost Estimation and Simple Payback Period Analysis of an Electrodialysis System

This cost evaluation report for an electrodialysis system incorporates the eight bulleted elements listed in Section 4.5 and calculates a simple payback period.

The technology used in this illustration is an electrodialysis system that recovers nickel (as nickel sulfate) and removes other dissolved solids from rinsewater, allowing the recovered water to be reused as rinsewater in the nickel electroplating line. The technology eliminates the generation of wastewater requiring treatment and off-site disposal of sludge containing hazardous levels of nickel. It also allows the recovered nickel sulfate to be reused in the electroplating bath. The cost analysis will estimate the years to pay back the cost of purchasing and installing the electrodialysis system based on the annual savings realized.

B.1 Defining the Cost Objectives and Data Collection Methods

The first element is to define the objectives of the cost analysis and to describe the methods used to accomplish the objectives, as well as the limitations of the testing. In this example, the objective of the cost analysis is to estimate the cost of the electrodialysis treatment and compare it with the baseline option. The baseline option is treating rinsewater in the on-site wastewater treatment plant, discharging the treated effluent to a sewer, and disposing of sludge at an off-site permitted facility. The cost analysis will estimate the time (years) required to pay back the cost of purchasing and installing the electrodialysis system, based on the annual O&M savings realized.

For this test, the electrodialysis system was operated in a user's plant for three months to generate performance and cost data. The plant's historical records were used to estimate the wastewater treatment costs, fresh water supply, and chemical costs prior to the installation of the electrodialysis system. Process water makeup, energy costs and maintenance costs were monitored during the test.

The short-term nature of testing limits the direct observation of long-term maintenance costs, which may be significant due to relatively high maintenance requirements. Also, the testing was conducted at one nickel-plating operation; costs incurred during installation and O&M savings may differ between users operating the electrodialysis system at other facilities.

B.2 Describing the Design Basis

The next element is to describe the design basis of the technology. The equipment specifications and operating parameters for the electrodialysis system and the baseline plating operation are presented in Table B-1.

B.3 Estimating Capital Investment

The next element is to determine the capital investment for the electrodialysis system. Table 2-1 in Section 2 of this document provides a checklist of capital items. For this example, the relevant capital items that apply include the cost of the purchased equipment (electrodialysis unit and associated pumps), installation (labor, materials), and startup/training (labor, materials). The source of the cost data should be provided so that the user can verify the information or compare the data with other cost estimates. For this case study, costs incurred during the purchase, installation, and startup of the technology were tracked for the demonstration. Labor unit costs were provided by the nickel-plating operating facility. Site preparation, utility connections/systems, and buildings/land are not applicable for this cost analysis. Regulatory/permitting costs are relevant for the baseline option, but were not included in the analysis, because they could not be determined from plant records. Contingency costs

Table B-1. Design Basis for the Electrodialysis System and Baseline (Plating) Operation

Electrodialysis System		Baseline (Plating) Operation (No Rinsewater Recovery)	
Annual throughput (rinsewater passing through the electrodialysis unit): 1,077,500 gal/yr		Annual throughput (rinsewater required in the plant): 1,077,500 gal/yr	
Makeup (fresh) water: 15,000 gal/yr		Fresh water supply: 1,077,500 gal/yr	
Nickel recovered from rinsewater: 171,000 lbs/yr (as nickel sulfate)		Nickel sulfate lost to sludge: 180,000 lbs/yr	
Operating parameters:	Two 8-hr shifts/day 5 days/week 50 weeks/year	Operating parameters:	Two 8-hr shifts/day 5 days/week 50 weeks/year

were not included because the actual (versus budgeted) capital investment estimate was available from plant records. Table B-2 summarizes the capital investment.

B.4 Estimating O&M Costs

Using Table 2-2 in Section 2 as a guide, the relevant O&M costs were determined. Table B-3 summarizes the annual O&M cost. For this illustration, O&M items that are considered relevant include materials (nickel sulfate), utilities (water, electricity, steam), labor (maintenance), and waste management (labor, treatment of waste, and disposal). Therefore, items such as materials (other than nickel sulfate), utilities, labor, insurance associated with the normal functions of the plating operation is not included in the estimate. Regulatory compliance associated with the generation of waste is not included, although it can be significant. Although the unit was operated for three months, the costs were extrapolated to obtain an annual cost. The unit cost and amount required for each component were estimated based upon the observations made during the pilot test, discussions with the vendor, and from historical plant records.

The estimate for wastewater treatment cost at the plant is shown in Table B-4. The volume of makeup water required for electrodialysis was determined by measuring level changes in the associated tanks. The electrical requirements were determined by the power requirements of the associated pumps and blowers.

B.5 Listing the Assumptions

This element is very important because it allows users to verify and compare the cost data with other cost estimates. Key assumptions that impact the cost analysis, such as operating parameters, also should be included. The following assumptions were used in the case study:

- All costs are in real (constant 2001) dollars. Discount rate is not used.
- Life of unit is 10 years.
- Labor benefits are not included in the labor unit cost.
- Cost of regulatory compliance associated with the hazardous nickel sludge generation of the baseline operation is not included.
- Electricity costs were estimated based on power requirements of the individual components. Some

Table B-2. Capital Investment for Electrodialysis System

	Electrodialysis System		
Item	Quantity	Unit Cost	Cost*
Purchased Equipment			
Electrodialysis membrane unit (including evaporator)	1	$83,500	$83,500
Installation			
Engineering Labor	50 hrs	$60/hr	$3,000
Technician Labor	100 hrs	$30/hr	$3,000
Materials (pumps, piping, valves, gauges, etc.)	1	$14,000	$14,000
Startup/Training			
Engineering Labor	25 hrs	$60/hr	$1,500
Technician Labor	200 hrs	$25/hr	$5,000
Total Capital Investment			**$110,000**

* For the design basis described in Table B-1.

Table B-3. Annual O&M Cost for Electrodialysis System and Baseline (Plating) Operation

	Electrodialysis System			Baseline Operation		
Item	Annual Quantity*	Unit Cost	Annual Cost	Annual Quantity*	Unit Cost	Annual Cost
Materials						
Makeup water	15,000 gal	\$4.19/1,000 gal	\$63	–	–	–
Chemicals, $NiSO_4$ purchased	180,000 lb	\$1/lb	\$180,000	180,000 lbs	\$1.00/lb	\$180,000
Chemicals, $NiSO_4$ recycled	–171,000 lb	\$1/lb	–\$171,000	–	–	–
Utilities						
Water	–	–	–	1,077,500 gal	\$4.19/1,000 gal	\$4,515
Steam	4.9×10^8 BTU	\$6/10^6 BTU	\$2,940	–	–	–
Electricity	78,600 kWh	\$0.118/kWh	\$9,275	–	–	–
Waste Management						
Wastewater treatment	–	–	–	1,077,500 gal**	\$14/1,000 gal***	\$15,085
Maintenance						
Service contract	4 visits	\$3,000/visit	\$12,000	–	–	–
Carbon change	6 events	\$1,020/event	\$6,120	–	–	–
Evaporator cleaning	12 events	\$120/event	\$1,440	–	–	–
Miscellaneous upkeep	1	\$1,000	\$1,000	–	–	–
Total Annual O&M Cost			**\$41,838**			**\$199,600**

* For the design basis described in Table B-1.
** See Table B-4 for the estimation of this unit cost number at this plant.
*** Wastewater generated by the targeted baseline (plating) operation only. This wastewater volume is just a fraction of the total volume treated annually by the plant.

Table B-4. Estimation of Wastewater Treatment Unit Cost at the Plant

Item	Annual Cost
Sludge disposal	\$72,000
Strip disposal	\$60,000
Misc. disposal	\$16,000
Labor	\$120,000
Chemicals	\$113,000
Maintenance	\$53,800
Total wastewater treatment costs at the plant	\$434,800
Wastewater volume treated per year at the plant	31,300,000 gal*
Unit cost of water treatment/gal	**\$14/1,000 gal**

* Includes wastewater from the baseline (plating) operation, as wells as from all other operations at this plant.

components, such as recirculating pumps, operate for a fraction of the time the entire recovery unit is in operation and have been adjusted appropriately.

- Steam costs were estimated from a requirement of 1,500 BTU of steam per pound of water evaporated. Observations during testing of the electrodialysis unit show 78 gal (550 lb) of water were lost to evaporation in one shift. This evaporative loss is included in the makeup water usage listed in Table B-3.

B.6 Listing Key Technical Factors that Impact Costs

Another important element is to identify key technical factors that impact costs. Technical factors impacting costs in this case study include the following:

- Water supply used during the testing was relatively low in hardness (calcium and magnesium content). In regions where water hardness is higher, evaporator cleaning (maintenance) may be required more frequently, with the associated higher cost.
- The plant in which the electrodialysis unit was tested had enough extra space to accommodate the electrodialysis equipment. In smaller plants, additional space (about 20 ft x 30 ft x 15 ft) may have to be created.

B.7 Listing the Intangible Benefits/Disadvantages

The intangible benefits or disadvantages of the technology are described, using Table 2-3 in Section 2 as a guideline. One intangible benefit is that the plant no longer has the potential liability associated with storage and transport of hazardous (nickel) sludge to a landfill. One disadvantage is that close monitoring of the electrodialysis unit is necessary because the system has a tendency to foul. Also, the energy consumption of the electrodialysis system is relatively high compared to the baseline operation.

B.8 Calculating Simple Payback Period

To calculate the simple payback of the electrodialysis system, the following equation was used:

$$\begin{bmatrix}\text{Simple}\\ \text{payback}\\ \text{period}\\ \text{(years)}\end{bmatrix} = \frac{\begin{bmatrix}\text{Capital investment}\\ \text{for the ETV technology}\end{bmatrix}}{\begin{bmatrix}\text{Net annual O\&M}\\ \text{after-tax savings}\end{bmatrix}} \qquad \text{(B-1)}$$

The capital investment estimate ($110,000) is obtained from Table B-2. The annual savings ($157,762) in operational costs are calculated by subtracting the annual O&M cost of the electrodialysis system from the annual O&M cost of the base nickel-plating operation (Table B-3). The payback period for the $110,000 system is approximately 1 year.

Appendix C

Illustration of Capital Investment/O&M Cost Estimation and Present Value Calculation for an Energy-Efficient Water Heater

A cost evaluation report for an energy-efficient water heater should incorporate the eight bulleted elements listed in Section 4.5. A PV is calculated for the energy-efficient water heater and compared with the PV of a conventional water heater.

The technology used in this illustration is an energy-efficient water heater for residential hot water generation.

C.1 Defining the Cost Objective and Data Collection Methods

In this example, the cost evaluation objective is to estimate the PV (i.e., life cycle) cost of the energy-efficient water heater, compare it with the PV of a conventional water heater (competing technology) in a residential setting, and estimate the savings (if any). Although the residential user was previously using a conventional water heater, the conventional heater is not considered a baseline technology because users are not expected to buy the energy-efficient heater until the life of his/her existing conventional heater is over. Therefore, the buyer's decision depends on a comparison of the two types of water heaters as competing technologies. The capital investment required for the conventional heater is therefore a relevant cost in this evaluation.

To generate performance and cost data, the energy-efficient unit was operated at a residential home for one week and compared to a conventional heater (competing technology) operated under the same conditions. Natural gas usage, recovery efficiency, and gallons of water used per day were measured during the test. However, the short-term nature of testing does not allow direct observation of the expected life of the new water heater. The test was conducted under specific operating conditions; savings obtained may differ among users operating the new water heater under different conditions.

C.2 Determining the Design Basis

The next element is to describe the design basis of the technology. The equipment specifications and operating parameters for the energy-efficient water heater and the conventional water heater are presented in Table C-1.

Table C-1. Design Basis for the Energy-Efficient Water Heater and the Conventional (Competing) Water Heater

Energy-Efficient Water Heater (40 gal, 2" water-blown insulation)	Conventional Water Heater (40 gal, 1.31 inches water-blown insulation)
Heat-recovery efficiency: 79.9%	Heat-recovery efficiency: 71.9%
Burner rate: 39,550 BTU/hr	Burner rate: 39,550 BTU/hr
Pilot burner rate: 450 BTU/hr	Pilot burner rate: 450 BTU/hr
Setpoint temperature: 135.0°F	Setpoint temperature: 135.0°F
Water usage: 50 gal/day	Water usage: 50 gal/day
Annual throughput (water usage): 18,250 gal/yr	Annual throughput (water usage): 18,250 gal/yr
Annual natural gas use (mBTU/yr): 21.314	Annual natural gas use (mBTU/yr): 23.919
Air temperature in vicinity of task: 67.5°F	Air temperature in vicinity of task: 67.5°F
Water inlet temperature: 58°F	Water inlet temperature: 58°F

C.3 Estimating Capital Investment

The next element is to determine the capital investment for the energy-efficient water heater and the conventional water heater. Table 2-1 in Section 2 of this document provides a checklist of capital items. For this example, the relevant capital items that apply include the cost of the purchased equipment (the water heater) and installation (labor and materials). The source of the cost data should be provided so that a user can verify the information or compare the data with other cost estimates. For this case study, a reasonable purchase price was used, that was based on information provided by the vendor. The actual purchase price will vary depending on where the user buys the water heater, local sales taxes, etc. The installation cost is the same for both heaters and is not included in the analysis. Site preparation, utility connections/systems, startup/training, regulatory/permitting, contingency, and buildings and land are not relevant and are not included in this cost analysis. Table C-2 summarizes the capital investment for the two technologies.

C.4 Estimating O&M Cost

The next element is to determine the relevant O&M costs of the two technologies, as described in Table 2-2 in Section 2. The relevant O&M items for this case study only include utilities (natural gas). Materials, labor, waste management, regulatory compliance, and insurance are not relevant, and are not included in this cost analysis. It is recommended that O&M costs be reported on an annual basis, regardless of the length of the verification test. The annual natural gas use is 21.314 mBTU/yr and 23.919 mBTU/yr for the energy-efficient water heater and the conventional water heater, respectively (Table C-3). For simplicity, the unit cost for natural gas in this case study was estimated based on the U.S. Department of Energy's (DOE) *Annual Energy Outlook*, which forecasts the cost of natural gas (in 1998 dollars) through the year 2020 (DOE, 2000). Assuming a unit of cost of $6.214/mBTU, the annual cost of natural gas usage is $132.45 for the efficient water heater and $148.64 for the conventional heater. Table C-3 summarizes the annual O&M cost.

C.5 Listing the Assumptions

This element is very important because it allows users to verify and compare the cost data with other cost estimates. Key assumptions that should be clearly stated when calculating net present value, annualized costs, or discounted payback period include: whether constant or nominal dollars are used (typically, constant dollars are recommended), the real discount rate, and when cash flows occur (typically at the end of the year). Other assumptions that impact the cost analysis, such as the expected life of the major equipment, also are included. The assumptions used in the case study are as follows:

- Total years of analysis is 9 years, based on the expected life of 9 years for both types of heater.
- All costs are in constant (real) 1998 dollars.
- The real discount rate (r) used is 6%.
- Cash flows occur at the end of each year.

Table C-2. Capital Investment for Case Study

	Energy-Efficient Water Heater			Conventional Water Heater		
Item	Quantity	Unit Cost	Cost*	Quantity	Unit Cost	Cost*
Purchased equipment						
Delivery of new water heater	1	$261	$261.00	1	$235.00	$235.00
Total Capital Investment			**$261.00**			**$235.00**

* Refer to the design basis in Table C-1.

Table C-3. Annual O&M Cost for the Energy-Efficient and the Conventional Water Heaters

	Energy-Efficient Water Heater			Conventional Water Heater		
Item	Annual Quantity	Unit Cost	Annual O&M Cost*	Annual Quantity	Unit Cost	Annual O&M Cost*
Utilities						
Natural Gas, mBTU	21.314	$6.214	$132.45	23.919	$6.214	$148.64
Total Annual O&M Cost	21.314		**$132.45**	23.919		**$148.64**

* Refer to the design basis in Table C-1.

- The expected fuel cost over the next 9 years of \$6.214/mBTU is based on DOE (2000). Actual savings will vary from user to user depending on the actual unit cost (price) of natural gas. The higher the unit cost of natural gas for the user, the greater the difference in PVs of the two heaters and the greater the savings realized.

C.6 Listing Key Technical Factors that Impact Costs

Another important element is to identify key technical factors that impact costs.

- The natural gas requirement is based on an average inlet water temperature of 58°F and an ambient temperature of 67.5°F. The actual inlet temperature of the water will vary seasonally through the year, and geographically for various users. Users who live in regions where the average water supply temperature is lower will incur higher heating requirements, and therefore, higher natural gas usage and cost. Air temperature in the vicinity of the water heater also will affect its efficiency.
- Users with an annual water usage greater than the 18,250 gal assumed here will experience greater savings; similarly, users with a lower annual water usage will experience lesser savings.

C.7 Listing the Intangible Benefits/Disadvantages

The intangible benefits or disadvantages of the technology should be described, using Table 2-3 of Section 2 as a guideline. The intangible benefit for this technology is a cleaner environment due to reduced carbon dioxide (greenhouse gas) emissions and reduction in the small amounts of NO_x and SO_2 emissions. Also, savings in total energy consumed nationally reduce dependence on imported fuel (assuming saved natural gas can reduce oil imports).

C.8 Calculating Present Value

The PV of the capital investment and annual O&M costs is estimated for each year for each technology using the following equations in a spreadsheet format.

$$\text{PV of cash flows} = \sum_{t=0}^{t=n} \frac{CF_t}{(1+r)^t} \qquad \text{(C-1)}$$

$$\begin{bmatrix}\text{PV of}\\ \text{cash}\\ \text{flows}\end{bmatrix} = CF_0 + \frac{CF_1}{(1+r)^1} + \frac{CF_2}{(1+r)^2} + \cdots + \frac{CF_n}{(1+r)^n} \qquad \text{(C-2)}$$

Table C-4 presents the spreadsheet results of the PV analysis. By subtracting the PV cost of the efficient water heater (\$1,161.88) from the PV cost of the conventional water heater (\$1,246.01), the PV of the savings realized over the life of the water heater is \$84.13. The *discounted payback period* is 2 years. The discounted payback period is the year in which the PV (cumulative) of the energy-efficient water heater becomes lower than the PV (cumulative) of the conventional water heater. As shown in Table C-4, this happens in Year 2.

C.9 Reference

U.S. Department of Energy. 2000. *Annual Energy Outlook*, DOE-E1A-0383. Washington, DC.

Table C-4. Spreadsheet Results of the Cost Analysis: PV of the Energy-Efficient and Conventional Water Heaters

Year (t)	0	1	2	3	4	5	6	7	8	9
					Energy-Efficient Water Heater					
Capital Investment (\$)	261.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Annual O&M Cost (\$)	–	132.45	132.45	132.45	132.45	132.45	132.45	132.45	132.45	132.45
Present Value (\$)	261.00	124.95	117.88	111.21	104.91	98.97	93.37	88.09	83.10	78.40
Cumulative PV (\$)	261.00	385.95	***503.83***	615.04	719.95	818.92	912.30	1,000.38	1,083.48	1,161.88
					Conventional Water Heater					
Capital Investment (\$)	235.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Annual O&M Cost (\$)	–	148.64	148.64	148.64	148.64	148.64	148.64	148.64	148.64	148.64
Present Value (\$)	235.00	140.23	132.29	124.80	117.74	111.07	104.79	98.85	93.26	87.98
Cumulative PV (\$)	235.00	375.23	***507.52***	632.32	750.05	861.13	965.91	1,064.77	1,158.03	1,246.01

Appendix D

Cost Evaluation References

If certain cost elements for a technology application are not available for an ETV pilot manager, some references are available that provide typical costs or cost guidance to help fill in the data gaps. Three common and useful references in the environmental, chemical, and process industries are a series of unit cost books: *Plant Design and Economics for Chemical Engineers* by Peters and Timmerhaus (1991); *The Richardson Rapid System for Process Plant Construction*, Richardson Engineering Services, Inc.; and the Environmental Cost Handling Options and Solutions (ECHOS) books published jointly by R.S. Means Company, Inc. and Talisman Partners, Ltd. When ETV testing is unable to measure certain cost elements (e.g., maintenance or installation costs) directly, these references can provide cost ranges based on broad industry experience. The texts referenced in this appendix do not represent a full literature review; other industry-specific standard references may be used.

Plant Design and Economics for Chemical Engineers, by Peters and Timmerhaus (1991)

This book is a widely used reference in the chemical industry and discusses the economic and engineering principles involved in the design and application of processing equipment. Because environmental technologies generally involve physical-chemical or biological processes for removing pollutants from a feed stream or for chemically characterizing soil, water, or air matrices, the principles in this book are generally applicable. Although the level of discussion in this book is probably too thorough for most ETV applications, there are some interesting rules of thumb in this book.

In the subsection titled “Purchased-Equipment Installation,” there is a table that provides typical installation costs for different types of equipment as a percentage of the purchased-equipment cost. For example, typical costs for installing pumps range from 25 to 60% of the purchase price of the pump; for metal tanks the installation cost is 30 to 60% of the price of the tank. If the nature of the testing or resources does not allow the ETV pilot to directly measure these numbers, these rules of thumb based on chemical industry experience can be used to estimate installation costs. In addition, these typical ranges, developed through broad industry experience, can serve as benchmarks to verify estimates developed by the ETV pilot manager.

In the absence of direct measurements, an ETV pilot manager can use some of the other rules of thumb for estimating the amount and cost of peripheral equipment (such as piping and electrical connections) required for various types of equipment, estimating the maintenance requirements for typical equipment, and for scaling up equipment based on capacity. For example, for estimating maintenance costs, industry experience suggests that typical annual maintenance costs range from 2 to 6% of fixed capital investment (FCI) for simple chemical processes, 5 to 9% of FCI for average processes under normal conditions, and 7 to 11% of FCI for complicated processes under severe operating conditions (e.g., corrosive environment or high temperatures).

The Richardson Rapid System for Process Plant Construction, by Richardson Engineering Services, Inc.

Another common cost estimating reference is *The Richardson Rapid Estimating System for Process Plant Construction*, which includes process plant construction estimating standards. It is similar to the cost data books produced by R.S. Means, Inc. and can be used to accurately estimate the cost of labor, materials, and equipment required for the installation and operation of ETV technologies. This reference is particularly applicable for technologies associated with chemical plants, manufacturing facilities, and water treatment plants, as well as general construction projects.
Estimates can be made quickly by using the estimating standards, which presents the worker-hours, composite

unit costs, and detailed line-item data developed for major areas such as Site Work, Mechanical and Electrical Construction, and Process Equipment. Estimating forms and procedures to adjust the standard estimates for site-specific conditions are included with each set of standards.

ECHOS Books by R.S. Means Company, Inc. and Talisman Partners, Ltd.

Sometimes, the ETV testing setup may not incorporate all the peripheral items required for installation and operation of the technology. For example, during the ETV test, a technician may measure and add chemicals to the process manually because it is convenient for the two-week period of the test and it may not be worthwhile investing in transfer pumps, metering instruments, and piping to add chemicals on a continuous basis. However, during actual operation in a user's facility, the user typically may be expected to install an automated chemical feed system. In this case, the cost of the technology should represent the typical use scenario. The ECHOS volumes *Environmental Remediation Cost Data 2001—Assemblies Cost Book* and *Environmental Remediation Cost Data 2001—Unit Cost Book* published by R.S. Means Company, Inc., with Talisman Partners, Ltd., are good references for supplementing the cost data collected during the ETV demonstration for items such as pumps, piping, instruments, and tanks. These volumes contain detailed unit price estimates of more than 4,000 assembly cost elements for labor, site demolition, site preparation, site improvement, site civil/mechanical utilities, site electrical utilities, and environmental restoration activities.

Other cost data books published solely by R.S. Means Company that pilots may find helpful include:

- *Means Building Construction Cost Data 2001*
- *Means Electrical Cost Data 2001*
- *Means Facilities Construction Cost Data 2001*
- *Means Mechanical Cost Data 2001*
- *Means Plumbing Cost Data 2001*.

These cost guides can be used by pilot managers to save time in researching the cost of many of the peripheral equipment and materials needed for the installation and operation of the technology by a typical user. The prices of materials, labor, and equipment within these databases have been compiled based on a large number of quotes from different manufacturers and can be used in the absence of direct quotes from the manufacturers of such peripherals.

Other Cost Estimation References

Waste Treatment Technologies

United States Environmental Protection Agency. 1995. *Detailed Costing Document for the Centralized Waste Treatment Industry*. Office of Water. EPA-821-R-95-002. January.

Air Pollution Control

United States Environmental Protection Agency. 1996. *OAQPS Control Cost Manual*, Fifth Edition Office of Air Quality Planning and Standards, Research Triangle Park, NC. EPA-453-B-96-001. February.

Process and Utility Industries

American Association of Cost Engineers (AACE, Inc.). 1990. *AACE Recommended Practices and Standards for Cost Estimation, Cost Control, Planning and Scheduling, and Project Management*. November.

Appendix E

Time Value of Money Table

Table E-1. Present Value of Annuity Factors* Calculated for Different Discount Rates (r) and Number of Years (n)

Number of Years (n)	Discount Rate (r)														
	0.5%	1%	1.5%	2%	3%	4%	5%	6%	7%	8%	10%	12%	15%	20%	25%
1	0.99502	0.99010	0.98522	0.98039	0.97087	0.96154	0.95238	0.94340	0.93458	0.92593	0.90909	0.89286	0.86957	0.83333	0.80000
2	1.98510	1.97040	1.95588	1.94156	1.91347	1.88609	1.85941	1.83339	1.80802	1.78326	1.73554	1.69005	1.62571	1.52778	1.44000
3	2.97025	2.94099	2.91220	2.88388	2.82861	2.77509	2.72325	2.67301	2.62432	2.57710	2.48685	2.40183	2.28323	2.10648	1.95200
4	3.95050	3.90197	3.85438	3.80773	3.71710	3.62990	3.54595	3.46511	3.38721	3.31213	3.16987	3.03735	2.85498	2.58873	2.36160
5	4.92587	4.85343	4.78264	4.71346	4.57971	4.45182	4.32948	4.21236	4.10020	3.99271	3.79079	3.60478	3.35216	2.99061	2.68928
6	5.89638	5.79548	5.69719	5.60143	5.41719	5.24214	5.07569	4.91732	4.76654	4.62288	4.35526	4.11141	3.78448	3.32551	2.95142
7	6.86207	6.72819	6.59821	6.47199	6.23028	6.00205	5.78637	5.58238	5.38929	5.20637	4.86842	4.56376	4.16042	3.60459	3.16114
8	7.82296	7.65168	7.48593	7.32548	7.01969	6.73274	6.46321	6.20979	5.97130	5.74664	5.33493	4.96764	4.48732	3.83716	3.32891
9	8.77906	8.56602	8.36052	8.16224	7.78611	7.43533	7.10782	6.80169	6.51523	6.24689	5.75902	5.32825	4.77158	4.03097	3.46313
10	9.73041	9.47130	9.22218	8.98259	8.53020	8.11090	7.72173	7.36009	7.02358	6.71008	6.14457	5.65022	5.01877	4.19247	3.57050
11	10.67703	10.36763	10.07112	9.78685	9.25262	8.76048	8.30641	7.88687	7.49867	7.13896	6.49506	5.93770	5.23371	4.32706	3.65640
12	11.61893	11.25508	10.90751	10.57534	9.95400	9.38507	8.86325	8.38384	7.94269	7.53608	6.81369	6.19437	5.42062	4.43922	3.72512
13	12.55615	12.13374	11.73153	11.34837	10.63496	9.98565	9.39357	8.85268	8.35765	7.90378	7.10336	6.42355	5.58315	4.53268	3.78010
14	13.48871	13.00370	12.54338	12.10625	11.29607	10.56312	9.89864	9.29498	8.74547	8.24424	7.36669	6.62817	5.72448	4.61057	3.82408
15	14.41662	13.86505	13.34323	12.84926	11.93794	11.11839	10.37966	9.71225	9.10791	8.55948	7.60608	6.81086	5.84737	4.67547	3.85926
16	15.33993	14.71787	14.13126	13.57771	12.56110	11.65230	10.83777	10.10590	9.44665	8.85137	7.82371	6.97399	5.95423	4.72956	3.88741
17	16.25863	15.56225	14.90765	14.29187	13.16612	12.16567	11.27407	10.47726	9.76322	9.12164	8.02155	7.11963	6.04716	4.77463	3.90993
18	17.17277	16.39827	15.67256	14.99203	13.75351	12.65930	11.68959	10.82760	10.05909	9.37189	8.20141	7.24967	6.12797	4.81219	3.92794
19	18.08236	17.22601	16.42617	15.67846	14.32380	13.13394	12.08532	11.15812	10.33560	9.60360	8.36492	7.36578	6.19823	4.84350	3.94235
20	18.98742	18.04555	17.16864	16.35143	14.87747	13.59033	12.46221	11.46992	10.59401	9.81815	8.51356	7.46944	6.25933	4.86958	3.95388
22	20.78406	19.66038	18.62082	17.65805	15.93692	14.45112	13.16300	12.04158	11.06124	10.20074	8.77154	7.64465	6.35866	4.90943	3.97049
24	22.56287	21.24339	20.03041	18.91393	16.93554	15.24696	13.79864	12.55036	11.46933	10.52876	8.98474	7.78432	6.43377	4.93710	3.98111
26	24.32402	22.79520	21.39863	20.12104	17.87684	15.98277	14.37519	13.00317	11.82578	10.80998	9.16095	7.89566	6.49056	4.95632	3.98791
28	26.06769	24.31644	22.72672	21.28127	18.76411	16.66306	14.89813	13.40616	12.13711	11.05108	9.30657	7.98442	6.53351	4.96967	3.99226
30	27.79405	25.80771	24.01584	22.39646	19.60044	17.29203	15.37245	13.76483	12.40904	11.25778	9.42691	8.05518	6.56598	4.97894	3.99505

* The numbers in this table represent the values of $\sum_{t=1}^{n} \frac{1}{(1+r)^t}$.

Appendix F

Unit Annualized Cost

The unit annualized cost is calculated by dividing the total annualized cost by the annual throughput (Equation F-1). As described in Section 4.1, the total annualized cost of a technology application is calculated by summing the annualized capital investment and the annual O&M costs associated with a technology for a given design basis.

$$\text{Unit annualized cost} = \frac{\text{Total annualized cost}}{\text{Annual throughput}} \qquad \text{(F-1)}$$

The annual throughput could be the gallons of wastewater treated, the number of samples analyzed, etc. Unit annualized cost is easy to understand and provides a quick way of comparing several technologies. For example, in the case of a new field characterization tool, potential users could quickly compare the cost per sample for the new field screening tool with the cost per sample incurred by sending samples to an off-site laboratory for analysis. However, because unit annualized cost depends on the design basis (i.e., equipment capacity, annual throughput), unit annualized cost also is the most likely to be misinterpreted. For example, a new water treatment unit may claim to treat water at a unit cost of $0.50/gal. But this may be based on the assumption that the new equipment will be sized and applied to a plant that treats 1,000,000 gal of water per year. For smaller users, who do not have the benefits of such economies of scale, the unit costs could be much higher. If the unit annualized costs of the two technologies are being compared, the pilot managers should ensure that estimates for both technologies were prepared on the same design basis.

Potential users may take the unit annualized cost number presented for the ETV technology and extrapolate it in a proportionate (linear) fashion to various levels of throughput. One way to avoid this misinterpretation is to present a graph of unit annualized cost versus throughput. Instead of presenting a single unit cost number, this graph allows potential users to estimate costs and compare technologies based on their anticipated throughput. Figure F-1 is an illustration of unit annualized cost versus throughput.

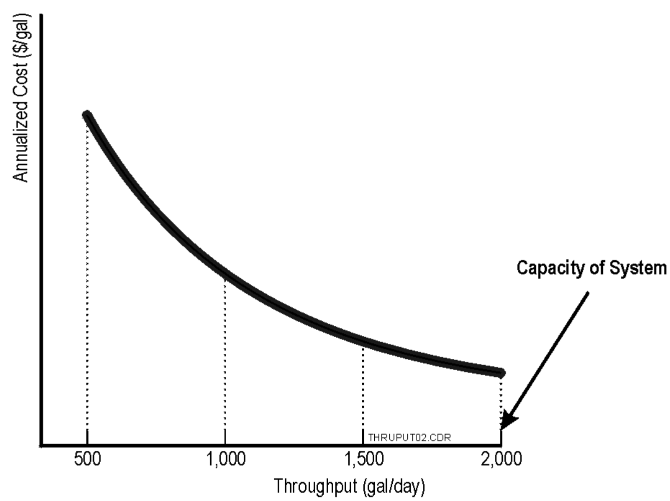

Figure F-1. Illustration of Unit Annualized Cost versus Throughput