EPA Manual for the Assessment of Reduction and Recycling Opportunities for Hazardous Waste (ARROW Project)

ADMINISTERED BY

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Users are encouraged to duplicate those portions of the manual as needed to implement a waste minimization program. Organizations interested in publishing and distributing the entire manual should contact the Alternative Technologies Division, Hazardous Waste Engineering Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268, to obtain a reproducible master.

Foreword

The term, "waste minimization" is heard increasingly at meetings and conferences of individuals working in the field of hazardous waste management. Waste minimization is an umbrella term that includes the first two categories of the EPA's preferred hazardous waste management strategy which is shown below:

1. Source Reduction: Reduce the amount of waste at the source, through changes in industrial processes.
2. Recycling: Reuse and recycle wastes for the original or some other purpose, such as materials recovery or energy production.
3. Incineration/Treatment: Destroy, detoxify, and neutralize wastes into less harmful substances.
4. Secure Land Disposal: Deposit wastes on land using volume reduction, encapsulation, leachate containment, monitoring, and controlled air and surface/subsurface waste releases.

In carrying out its program to encourage the adoption of waste minimization, the Hazardous Waste Engineering Research Laboratory has supported the development of a recommended procedure for identifying waste minimization applications. This manual describes that procedure and will be of interest to those responsible for reducing waste streams, and to those interested in learning about waste minimization in general.

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Section 1
Introduction

Waste minimization (WM) has been successful for many organizations. By following the procedures outlined in this manual, a waste generator can:

- Save money by reducing waste treatment and disposal costs, raw material purchases, and other operating costs.
- Meet state and national waste minimization policy goals.
- Reduce potential environmental liabilities.
- Protect public health and worker health and safety.
- Protect the environment.

Waste minimization is a policy specifically mandated by the U. S Congress in the 1984 Hazardous and Solid Wastes Amendments to the Resource Conservation and Recovery Act (RCRA). This mandate, coupled with other RCRA provisions that have led to unprecedented increases in the costs of waste management, have heightened general interest in waste minimization. A strong contributing factor has been a desire on the part of generators to reduce their environmental impairment liabilities under the provisions of the Comprehensive Environmental Response, Compensation, and Liabilities Act (CERCLA, or "Superfund"). Because of these increasing costs and liability exposure, waste minimization has become more and more attractive economically.

The following terms, used throughout this manual, are defined below:

Waste Minimization (WM). In the working definition currently used by EPA, waste minimization consists of *source reduction* and *recycling*. This concept of waste minimization is presented in Figure 1-1. Of the two approaches, source reduction is usually preferable to recycling from an environmental perspective. Source reduction and recycling each are comprised of a number of practices and approaches which are illustrated in Figure 1-2.

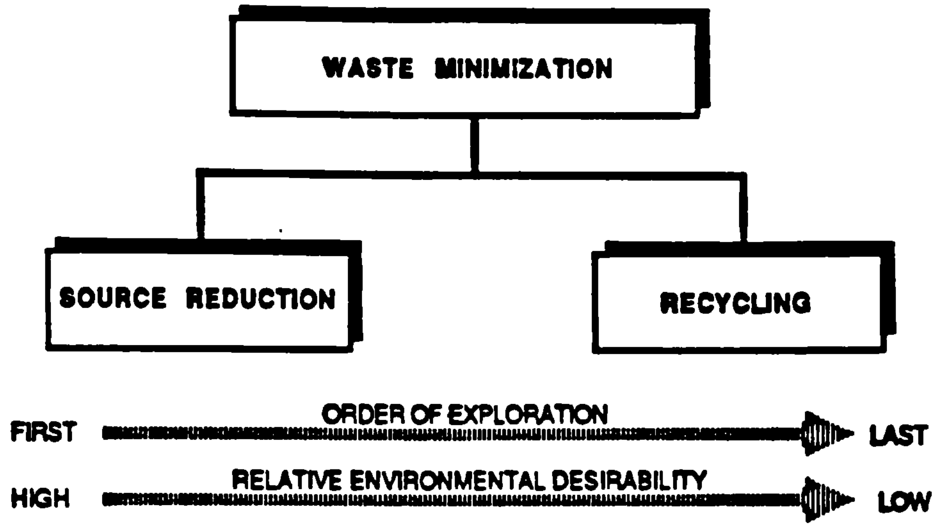
The present focus of WM activities is on hazardous wastes, as defined in RCRA. However, it is important that all pollutant emissions into air, water and land be considered as part of a waste minimization program. The transfer of pollutants from one medium to another is not waste minimization. For example, the removal of organics from wastewater using activated carbon, in and of itself, is not waste minimization, since the pollutants are merely transferred from one medium (wastewater) to another (carbon, as solid waste).

Waste minimization program (WMP). The RCRA regulations require that generators of hazardous waste "have a program in place to reduce the volume and toxicity of waste generated to the extent that is economically practical." A waste minimization program is an organized, comprehensive, and continual effort to systematically reduce waste generation. Generally, a program is established for the organization as a whole. Its components may include specific waste minimization projects and may use waste minimization assessments as a tool for determining where and how waste can be reduced. A waste minimization program should reflect the goals and policies for waste minimization set by the organization's management. Also, the program should be an ongoing effort and should strive to make waste minimization part of the company's operating philosophy. While the main goal of a waste minimization program is to reduce or eliminate waste, it may also bring about an improvement in a company's production efficiency.

EPA will publish separate guidance on the elements of effective waste minimization programs. This guidance will discuss the following elements likely to be found in an effective WM program:

- Top management support
- Explicit program scope and objectives
- Accurate waste accounting
- Accurate cost accounting
- Pervasive waste minimization philosophy
- Technology transfer

Waste minimization assessment (WMA). A waste minimization assessment is a systematic planned procedure with the objective of identifying ways to reduce or eliminate waste. The steps involved in conducting a waste minimization assessment are outlined in Figure 1-3. The assessment consists of a careful review of a plant's operations and waste streams, and the selection of specific areas to assess. After a specific waste stream or area is established as the WMA focus, a number of options with the potential to minimize waste are developed and screened. Third, the technical and economic feasibility of the selected options are evaluated. Finally, the most promising options are selected for implementation.



WASTE MINIMIZATION

The reduction, to the extent feasible, of hazardous waste that is generated or subsequently treated, stored or disposed of. It includes any source reduction or recycling activity undertaken by a generator that results in either (1) the reduction of total volume or quantity of hazardous waste or (2) the reduction of toxicity of the hazardous waste, or both, so long as such reduction is consistent with the goal of minimizing present and future threats to human health and the environment (EPA's Report to Congress, 1986, EPA/530-SW-86-033).

SOURCE REDUCTION

Any activity that reduces or eliminates the generation of hazardous waste at the source, usually within a process (op. cit.).

RECYCLING

A material is "recycled" if it is used, reused, or reclaimed (40 CFR 261.1 (c) (7)). A material is "used or reused" if it is either (1) employed as an ingredient (including its use as an intermediate) to make a product; however a material will not satisfy this condition if distinct components of the material are recovered as separate end products (as when metals are recovered from metal containing secondary materials) or (2) employed in a particular function as an effective substitute for a commercial product (40 CFR 261.1 (c) (5)). A material is "reclaimed" if it is processed to recover a useful product or if it is regenerated. Examples include the recovery of lead values from spent batteries and the regeneration of spent solvents (40 CFR 261.1 (c) (4)).

Figure 1-1. Waste Minimization Definitions

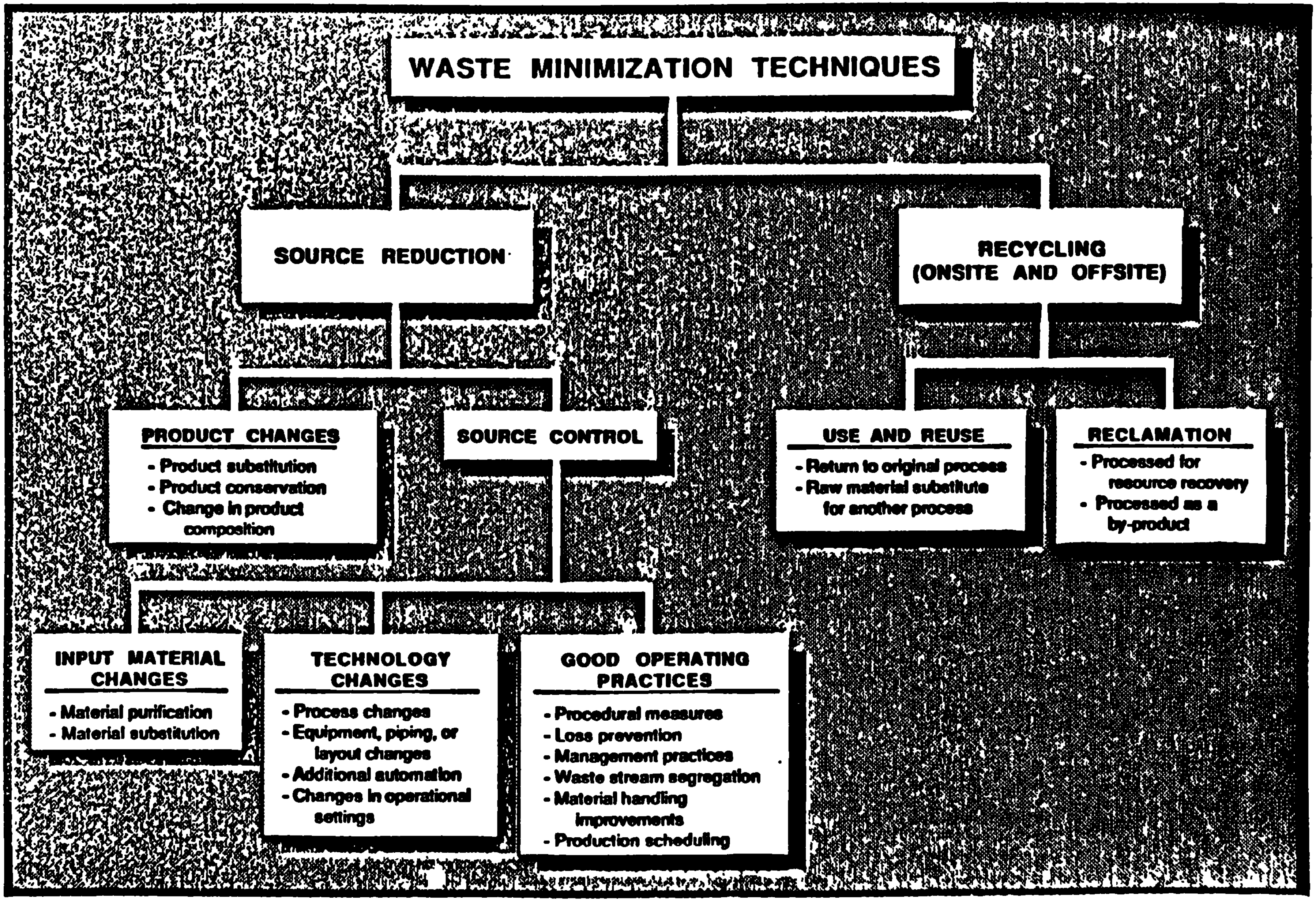
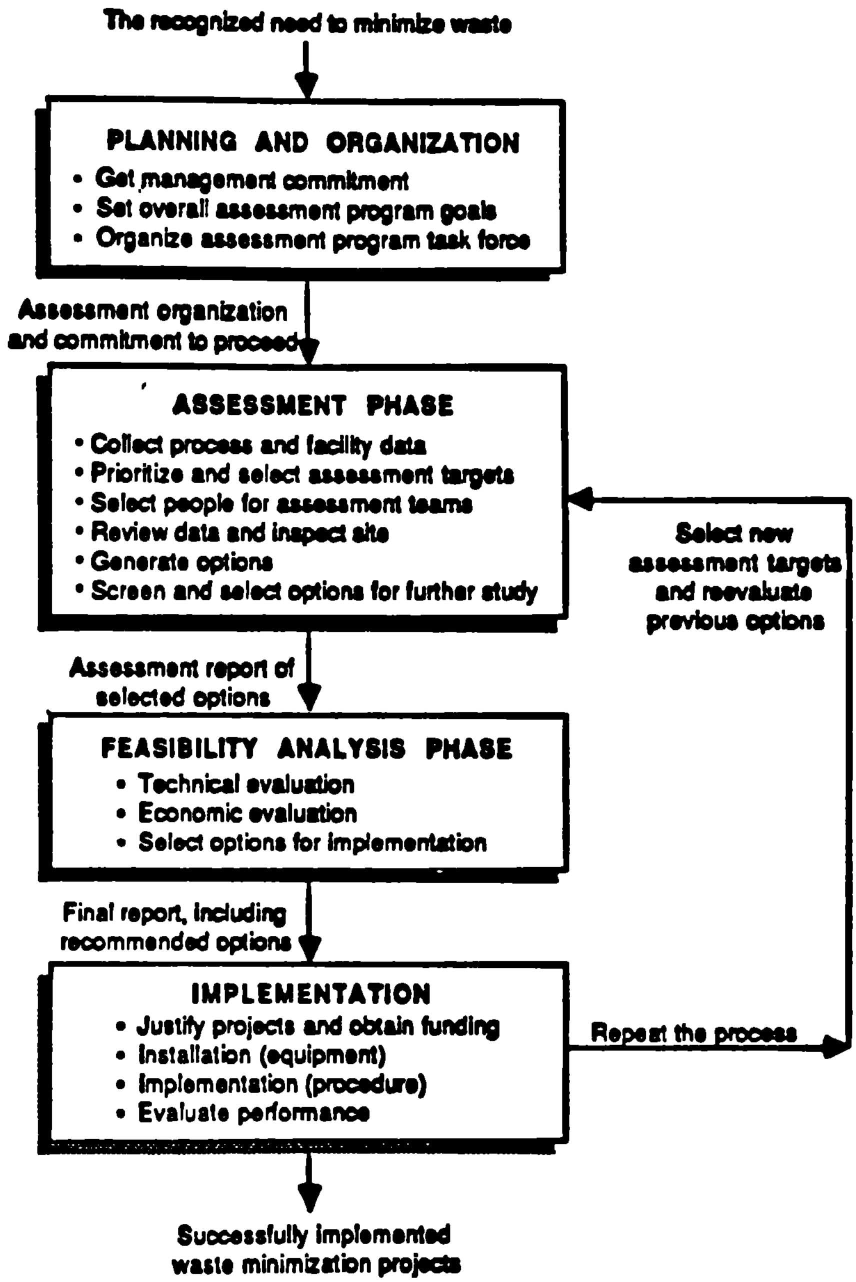


Figure 1-2. Waste Minimization Techniques

Figure 1-3. The Waste Minimization Assessment Procedure



Incentives for Waste Minimization

There are a number of compelling incentives for minimizing waste. Table 1-1 summarizes some of these incentives.

Table 1-1. Waste Minimization Incentives

Economics
- Landfill disposal cost increases.
- Costly alternative treatment technologies.
- Savings in raw material and manufacturing costs.

Regulations
- Certification of a WM program on the hazardous waste manifest.
- Biennial WM program reporting.
- Land disposal restrictions and bans.
- Increasing permitting requirements for waste handling and treatment.

Liability
- Potential reduction in generator liability for environmental problems at both onsite and offsite treatment, storage, and disposal facilities.
- Potential reduction in liability for worker safety.

Public Image and Environmental Concern
- Improved image in the community and from employees.
- Concern for improving the environment.

EPA intends to publish a manual entitled "Waste Minimization Benefits Handbook" which will discuss in detail the cost/benefit analyses of WM options.

About this manual

This manual has been prepared for those responsible for planning, managing, and implementing waste minimization activities at the plant and corporate levels. The manual concentrates on procedures that motivate people to search, screen, and put into practice measures involving administrative, material, or technology changes that result in decreased waste generation. It is also a source of concepts and ideas for developing and implementing a waste minimization program.

The manual is organized as follows:

- Section 2 outlines the planning and organizational aspects that provide a necessary foundation for a waste minimization assessment.

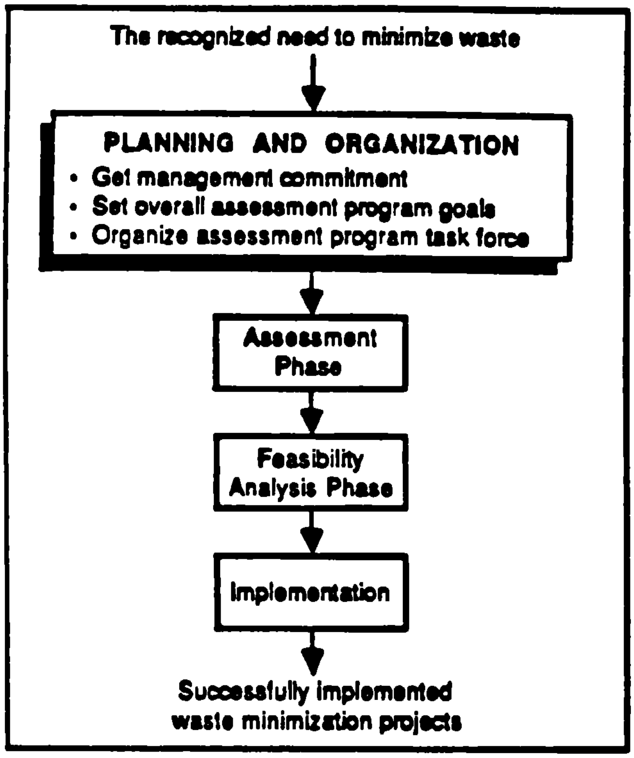
- Section 3 describes the assessment phase, including collecting information, selecting assessment targets, selecting assessment teams, and identifying potential WM options.

- Section 4 discusses the methods for evaluating options for technical and economic feasibility.

- Section 5 describes the implementation of attractive options: obtaining funding, installation and implementation, and measuring the effectiveness of implemented options.

A set of worksheets useful in carrying out assessments is included in Appendix A. Because individual generators' circumstances and needs vary widely, users of this manual are encouraged to modify the procedures and worksheets to fit their unique requirements. The manual is intended to serve as a point of departure, rather than as a set of rigid requirements. Accordingly, Appendix B presents a simplified set of worksheets that are designed to assist generators who are interested in performing only preliminary assessments. These worksheets also provide a useful framework for conducting assessments for small businesses and small quantity generators.

A sample assessment is presented in Appendix C. Appendix D describes waste streams from common industrial operations. Appendix E is a catalog and brief description of waste minimization techniques applicable in a number of common waste-intensive operations. Appendix F is a list of addresses and telephone numbers of state programs for technical assistance in waste minimization. Appendix G presents describes a method for screening and rating potential waste minimization options for further study. Finally, an example of an economic feasibility analysis of a large waste minimization project is presented in Appendix H.



This section discusses factors that are important to the success of a waste minimization program. Because a comprehensive WM program affects many functional groups within a company, the program needs to bring these different groups together to reduce wastes. The formality of the program depends upon the size and complexity of the organization and its waste problems. The program structure must be flexible enough to accommodate unforeseen changes. The developmental activities of a WM program include:

- getting management commitment
- setting WM goals
- staffing the program task force

Getting Management Commitment

The management of a company will support a waste minimization program if it is convinced that the benefits of such a program will outweigh the costs. The potential benefits include economic advantages, compliance with regulations, reduction in liabilities associated with the generation of wastes, improved public image, and reduced environmental impact.

The objectives of a WM program are best conveyed to a company's employees through a formal policy statement or management directive. A company's upper management is responsible for establishing a formal commitment throughout all divisions of the organization. The person in charge of the company's environmental affairs is responsible to advise management of the importance of waste minimization and the need for this formal commitment. An example of a formal policy statement follows:

CORPORATE ENVIRONMENTAL POLICY

[A major chemical company]..."is committed to continue excellence, leadership, and stewardship in protecting the environment. Environmental protection is a primary management responsibility, as well as the responsibility of every employee.

In keeping with this policy, our objective as a company is to reduce waste and achieve minimal adverse impact on the air, water, and land through excellence in environmental control.

The Environmental Guidelines include the following points:

- Environmental protection is a line responsibility and an important measure of employee performance. In addition, every employee is responsible for environmental protection in the same manner he or she is for safety.
- Minimizing or eliminating the generation of waste has been and continues to be a prime consideration in research, process design, and plant operations; and is viewed by management like safety, yield, and loss prevention.
- Reuse and recycling of materials has been and will continue to be given first consideration prior to classification and disposal of waste."

Involve Employees

Although management commitment and direction are fundamental to the success of a waste minimization program, commitment throughout an organization is necessary in order to resolve conflicts and to remove barriers to the WM program. Employees often cause the generation of waste, and they can contribute to the overall success of the program. Bonuses, awards, plaques, and other forms of recognition are often used to provide motivation, and to boost employee cooperation and participation. In some companies, meeting the waste minimization goals is used as a measure for evaluating the job performance of managers and employees.

Cause Champions

Any WM program needs one or more people to champion the cause. These "cause champions" help overcome the inertia present when changes to an existing operation are proposed. They also lead the WM program, either formally or informally. An environmental engineer, production manager, or plant process engineer may be a good candidate for this role. Regardless of who takes the lead, this cause champion must be given enough authority to effectively carry out the program.

Organizing a WM Program: The Program Task Force

The WM program will affect a number of groups within a company. For this reason, a program task force should be assembled. This group should include members of any group or department in the company that has a significant interest in the outcome of the program. Table 2-4 at the end of this section and Worksheet 3 in Appendix A lists departments or groups of a typical manufacturing company that should be involved in the program.

The formality or informality of the WM program will depend on the nature of the company. The program in a large highly structured company will probably develop to be quite formal, in contrast to a small company, or a company in a dynamic industry, where the organizational structure changes frequently.

Table 2-1 lists the typical responsibilities of a WM program task force. It will draw on expertise within the company as required. The scope of the program will determine whether full-time participation is required by any of the team members.

Table 2-1. Responsibilities of the WM Program Task Force

- Get commitment and a statement of policy from management.
- Establish overall WM program goals.
- Establish a waste tracking system.
- Prioritize the waste streams or facility areas for assessment.
- Select assessment teams.
- Conduct (or supervise) assessments.
- Conduct (or monitor) technical/economic feasibility analyses of favorable options.
- Select and justify feasible options for implementation.
- Obtain funding and establish schedule for implementation.
- Monitor (and/or direct) implementation progress.
- Monitor performance of the option, once it is operating.

In a small company, several people at most will be all that are required to implement a WM program. Include the people with responsibility for production, facilities, maintenance, quality control, and waste treatment and disposal on the team. It may be that a single person, such as the plant manager, has all of these responsibilities at a small facility. However, even at a small facility, at least two people should be involved to get a variety of viewpoints and perspectives.

Some larger companies have developed a system in which assessment teams periodically visit different facilities within the company. The benefits result through sharing the ideas and experiences with other divisions. Similar results can be achieved with periodic in-house seminars, workshops, or meetings. A large chemical manufacturer held a corporate-wide symposium in 1986 dealing specifically with waste minimization. The company has also developed other programs to increase company-wide awareness of waste minimization, including an internally published newsletter and videotape.

Setting Goals

The first priority of the WM program task force is to establish goals that are consistent with the policy adopted by management. Waste minimization goals can be qualitative, for example, "a significant reduction of toxic substance emissions into the environment." However, it is better to establish measurable, quantifiable goals, since qualitative goals can be interpreted ambiguously. Quantifiable goals establish a clear guide as to the degree of sucess expected of the program. A major chemical company has adopted a corporate-wide goal of 5% waste reduction per year. In addition, each facility within the company has set its own waste minimization goals.

As part of its general policy on hazardous waste, a large defense contractor has established an ambitious corporate-wide goal of zero discharge of hazardous wastes from its facilities by the end of 1988. Each division within the corporation is given the responsibility and freedom to develop its own program (with intermediate goals) to meet this overall goal. This has resulted in an extensive investigation of procedures and technologies to accomplish source reduction, recycling and resource recovery, and onsite treatment.

Table 2-2 lists the qualities that goals should possess. It is important that the company's overall waste minimization goals be incorporated into the appropriate individual departmental goals.

The goals of the program should be reviewed periodically. As the focus of the WM program becomes more defined, the goals should be changed to reflect any changes. Waste minimization assessments are not intended to be a one-time project. Periodic reevaluation of goals is recommended due to changes, for example, in available technology, raw

Table 2-2. Attributes of Effective Goals

- ACCEPTABLE to those who will work to achieve them.
- FLEXIBLE and adaptable to changing requirements.
- MEASURABLE over time.
- MOTIVATIONAL.
- SUITABLE to the overall corporate goals and mission.
- UNDERSTANDABLE.
- ACHIEVABLE with a practical level of effort.

Source: Pearce and Robinson, Strategic Management (1985)

material supplies, environmental regulations, and economic climate.

Overcoming Barriers

As it sets goals for waste minimization and then defines specific objectives that can be achieved, the program task force should recognize potential barriers. Although waste minimization projects can reduce operating costs and improve environmental compliance, they can lead to conflicts between different groups within the company. Table 2-3 lists examples of jurisdictional conflicts that can arise during the implementation of a waste minimization project.

In addition to jurisdictional conflicts related to these objective barriers, there are attitude-related barriers that can disrupt a WM program. A commonly held attitude is "If it ain't broke, don't fix it!" This attitude stems from the desire to maintain the status quo and avoid the unknown. It is also based on the fear that a new WM option may not work as advertised. Without the commitment to carefully conceive and implement the option, this attitude can become a self-fulfilling prophecy. Management must declare that "It is broke!"

Another attitude-related barrier is the feeling that "It just won't work!" This response is often given when a person does not fully understand the nature of the proposed option and its impact on operations. The danger here is that promising options may be dropped before they can be evaluated. One way to avoid this is to use idea-generating sessions (e.g., brainstorming). This encourages participants to propose a large number of options, which are individually evaluated on their merits.

An often-encountered barrier is the fear that the WM option will diminish product quality. This is particularly common in situations where unused feed materials are recovered from the waste and then recycled back to the process. The deterioration of product quality can be a valid concern if unacceptable concentrations of waste materials build up in the system. The best way to allay this concern is to set up a small-scale demonstration in the facility, or to observe the particular option in operation at another facility.

Table 2-3. Examples of Barriers to Waste Minimization

Production
- A new operating procedure will reduce waste but may also be a bottleneck that decreases the overall production rate.
- Production will be stopped while the new process equipment is installed.
- A new piece of equipment has not been demonstrated in a similar service. It may not work here.

Facilities/Maintenance
- Adequate space is not available for the installation of new equipment.
- Adequate utilities are not available for the new equipment.
- Engineering or construction manpower will not be available in time to meet the project schedule.
- Extensive maintenance may be required.

Quality Control
- More intensive QC may be needed.
- More rework may be required.

Client Relations/Marketing
- Changes in product characteristics may affect customer acceptance.

Inventory
- A program to reduce inventory (to avoid material deterioration and reprocessing) may lead to stockouts during high product demand.

Finance
- There is not enough money to fund the project.

Purchasing
- Existing stocks (or binding contracts) will delay the replacement of a hazardous material with a non-hazardous substitute.

Environmental
- Accepting another plant's waste as a feedstock may require a lengthy resolution of regulatory issues.

Waste Treatment
- Use of a new nonhazardous raw material will adversely impact the existing wastewater treatment facility.

Planning and Organization Summary

Table 2-4 provides a summary of the steps involved in planning and organizing a waste minimization program.

Assessment Worksheets

Appendix A includes a set of worksheets for use in planning and carrying out a waste minimization assessment, and implementing the selected options. Worksheet 1 summarizes the entire assessment procedure. Worksheets 2 and 3 are used to record the organization of the WM program task force and the individual assessment teams, respectively. Worksheet 3 includes a list of functions and departments that should be considered when organizing the assessment teams.

Table 2-4. Planning and Organization Activities Summary

SETTING UP THE PROGRAM

Get management commitment to:

- Establish waste minimization as a company goal.
- Establish a waste minimization program to meet this goal.
- Give authority to the program task force to implement this program.

Set overall goals for the program. These goals should be:

- ACCEPTABLE to those who will work to achieve them.
- FLEXIBLE to adapt to changing requirements.
- MEASURABLE over time.
- MOTIVATIONAL.
- SUITABLE to the overall corporate goals.
- UNDERSTANDABLE.
- ACHIEVABLE with a practical level of effort.

STAFFING THE PROGRAM TASK FORCE

Find a "cause champion", with the following attributes:

- Familiar with the facility, its production processes, and its waste management operations.
- Familiar with the people.
- Familiar with quality control requirements.
- Good rapport with management.
- Familiar with new production and waste management technology.
- Familiar with WM principles and techniques, and environmental regulations.
- Aggressive managerial style.

Get people who know the facility, processes, and procedures.

Get people from the affected departments or groups.

- Production.
- Facilities/Maintenance.
- Process Engineering.
- Quality Control.
- Environmental.
- Research and Development.
- Safety/Health.
- Marketing/Client Relations.
- Purchasing.
- Material Control/Inventory.
- Legal.
- Finance/Accounting.
- Information Systems.

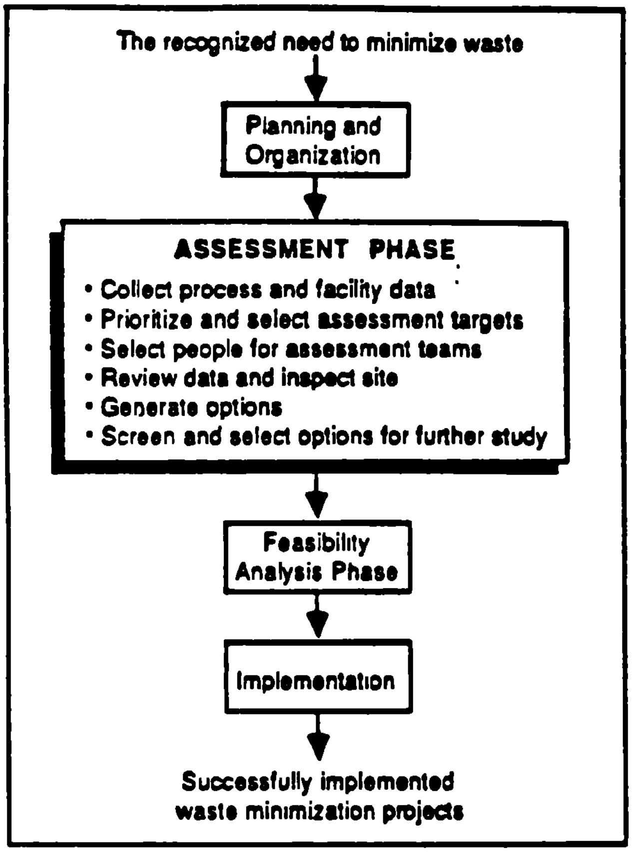
GETTING COMPANY-WIDE COMMITMENT

Incorporate the company's WM goals into departmental goals.

Solicit employee cooperation and participation.

Develop incentives and/or awards for managers and employees.

Section 3
Assessment Phase



The purpose of the assessment phase is to develop a comprehensive set of waste minimization options, and to identify the attractive options that deserve additional, more detailed analysis. In order to develop these WM options, a detailed understanding of the plant's wastes and operations is required. The assessment should begin by examining information about the processes, operations, and waste management practices at the facility.

Collecting and Compiling Data

The questions that this information gathering effort will attempt to answer include the following:

- What are the waste streams generated from the plant? And how much?
- Which processes or operations do these waste streams come from?
- Which wastes are classified as hazardous and which are not? What makes them hazardous?
- What are the input materials used that generate the waste streams of a particular process or plant area?
- How much of a particular input material enters each waste stream?
- How much of a raw material can be accounted for through fugitive losses?
- How efficient is the process?
- Are unnecessary wastes generated by mixing otherwise recyclable hazardous wastes with other process wastes?
- What types of housekeeping practices are used to limit the quantity of wastes generated?
- What types of process controls are used to improve process efficiency?

Table 3-1 lists information that can be useful in conducting the assessment. Reviewing this information will provide important background for understanding the plant's production and maintenance processes and will allow priorities to be determined. Worksheets 4 through 10 in Appendix A can be used to record the information about site characteristics, personnel, processes, input materials, products, and waste streams. Worksheets S2 through S6 in Appendix B are designed to record the same information, but in a more simplified approach.

Waste Stream Records

One of the first tasks of a waste minimization assessment is to identify and characterize the facility waste streams. Information about waste streams can come from a variety of sources. Some information on waste quantities is readily available from the completed hazardous waste manifests, which include the description and quantity of hazardous waste shipped to a TSDF. The total amount of hazardous waste shipped during a one-year period, for example, is a convenient means of measuring waste generation and waste reduction efforts. However, manifests often lack such information as chemical analysis of the waste, specific source of the waste, and the time period during which the waste was generated. Also, manifests do not cover wastewater effluents, air emissions, or nonhazardous solid wastes.

Other sources of information on waste str eams include biennial reports and NPDES (National Pollutant

Table 3-1. Facility Information for WM Assessments

Design Information

- Process flow diagrams
- Material and heat balances (both design balances and actual balances) for
  - production processes
  - pollution control processes
- Operating manuals and process descriptions
- Equipment lists
- Equipment specifications and data sheets
- Piping and instrument diagrams
- Plot and elevation plans
- Equipment layouts and work flow diagrams

Environmental Information

- Hazardous waste manifests
- Emission inventories
- Biennial hazardous waste reports
- Waste analyses
- Environmental audit reports
- Permits and/or permit applications

Raw Material/Production Information

- Product composition and batch sheets
- Material application diagrams
- Material safety data sheets
- Product and raw material inventory records
- Operator data logs
- Operating procedures
- Production schedules

Economic Information

- Waste treatment and disposal costs
- Product, utility, and raw material costs
- Operating and maintenance costs
- Departmental cost accounting reports

Other Information

- Company environmental policy statements
- Standard procedures
- Organization charts

Discharge Elimination System) monitoring reports. These NPDES monitoring reports will include the volume and constituents of wastewaters that are discharged. Additionally, toxic substance release inventories prepared under the "right to know" provisions of SARA Title III, Section 313 (Superfund Amendment and Reauthorization Act) may providevaluable information on emissions into all environmental media (land, water, and air).

Analytical test data available from previous waste evaluations and routine sampling programs can be helpful if the focus of the assessment is a particular chemical within a waste stream.

Flow Diagrams and Material Balances

Flow diagrams provide the basic means for identifying and organizing information that is useful for the assessment. Flow diagrams should be prepared to identify important process steps and to identify sources where wastes are generated. Flow diagrams are also the foundation upon which material balances are built.

Material balances are important for many WM projects, since they allow for quantifying losses or emissions that were previously unaccounted for Also, material balances assist in developing the following information:

- baseline for tracking progress of the WM efforts
- data to estimate the size and cost of additional equipment and other modifications
- data to evaluate economic performance

In its simplest form, the material balance is represented by the mass conservation principle:

$$\text{Mass in} = \text{Mass out} + \text{Mass accumulated}$$

The material balance should be made individually for all components that enter and leave the process. When chemical reactions take place in a system, there is an advantage to doing "elemental balances" for specific chemical elements in a system.

Material balances can assist in determining concentrations of waste constituents where analytical test data is limited. They are particularly useful where there are points in the production process where it is difficult (due to inaccessibility) or uneconomical to collect analytical data. A material balance can help determine if fugitive losses are occurring. For example, the evaporation of solvent from a parts cleaning tank can be estimated as the difference between solvent put into the tank and solvent removed from the tank.

To characterize waste streams by material balance can require considerable effort. However, by doing so, a more complete picture of the waste situation results. This helps to establish the focus of the WM activities and provides a baseline for measuring performance. Appendix D lists potential sources of waste from specific processes and operations.

Sources of Material Balance Information

By definition, the material balance includes both materials entering and leaving a process. Table 3-2 lists potential sources of material balance information.

Table 3-2. Sources of Material Balance Information

- Samples, analyses, and flow measurements of feed stocks, products, and waste streams
- Raw material purchase records
- Material inventories
- Emission inventories
- Equipment cleaning and validation procedures
- Batch make-up records
- Product specifications
- Design material balances
- Production records
- Operating logs
- Standard operating procedures and operating manuals
- Waste manifests

Material balances are easier, more meaningful, and more accurate when they are done for individual units, operations, or processes. For this reason, it is important to define the material balance envelope properly. The envelope should be drawn around the specific area of concern, rather than a larger group of areas or the entire facility. An overall material balance for a facility can be constructed from individual unit material balances. This effort will highlight interrelationships between units and will help to point out areas for waste minimization by way of cooperation between different operating units or departments.

Pitfalls in Preparing Material Balances

There are several factors that must be considered when preparing material balances in order to avoid errors that could significantly overstate or understate waste streams. The precision of analytical data and flow measurements may not allow an accurate measure of the stream. In particular, in processes with very large inlet and outlet streams, the absolute error in measurement of these quantities may be greater in magnitude than the actual waste stream itself. In this case, a reliable estimate of the waste stream cannot be obtained by subtracting the quantity of hazardous material in the product from that in the feed.

The time span is important when constructing a material balance. Material balances constructed over a shorter time span require more accurate and more frequent stream monitoring in order to close the balance. Material balances performed over the duration of a complete production run are typically the easiest to construct and are reasonably accurate. Time duration also affects the use of raw material purchasing records and onsite inventories for calculating input material quantities. The quantities of materials *purchased* during a specific time period may not necessarily equal the quantity of materials *used* in production during the same time period, since purchased materials can accumulate in warehouses or stockyards.

Developing material balances around complex processes can be a complicated undertaking, especially if recycle streams are present. Such tasks are usually performed by chemical engineers, often with the assistance of computerized process simulators.

Material balances will often be needed to comply with Section 313 of SARA (Superfund Amendment and Reauthorization Act of 1986) in establishing emission inventories for specific toxic chemicals. EPA's Office of Toxic Substances (OTS) has prepared a guidance manual entitled Estimating Releases and Waste Treatment Efficiencies for the Toxic Chemicals Inventory Form (EPA 560/4-88-02). The OTS manual contains additional information for developing material balances for the listed toxic chemicals. The information presented in this manual applies to a WM assessment when the material balances are for individual operations being assessed rather than an overall facility, when the variations in flow over time is accounted for, and when the data is used from separate streams rather than from aggregate streams.

Tracking Wastes

Measuring waste mass flows and compositions is something that should be done periodically. By tracking wastes, seasonal variations in waste flows or single large waste streams can be distinguished from continual, constant flows. Indeed, changes in waste generation cannot be meaningfully measured unless the information is collected both before and after a waste minimization option is implemented. Fortunately, it is easier to do material balances the second time, and gets even easier as more are done because of the "learning curve" effect. In some larger companies, computerized database systems have been used to track wastes. Worksheets 9 and 10 in Appendix A (and Worksheet S6 in Appendix B) provide a means of recording pertinent waste stream characteristics.

Prioritizing Waste Streams and/or Operations to Assess

Ideally, all waste streams and plant operations should be assessed. However, prioritizing the waste streams and/or operations to assess is necessary when available funds and/or personnel are limited. The WM assessments should concentrate on the most important waste problems first, and then move on to the lower priority problems as the time, personnel, and budget permit.

Setting the priorities of waste streams or facility areas to assess requires a great deal of care and attention, since this step focuses the remainder of the assessment activity. Table 3-3 lists important criteria to consider when setting these priorities.

Table 3-3. Typical Considerations for Prioritizing Waste Streams to Assess

- Compliance with current and future regulations.
- Costs of waste management (treatment and disposal).
- Potential environmental and safety liability.
- Quantity of waste.
- Hazardous properties of the waste (including toxicity, flammability, corrosivity, and reactivity).
- Other safety hazards to employees.
- Potential for (or ease of) minimization.'
- Potential for removing bottlenecks in production or waste treatment.
- Potential recovery of valuable by-products.
- Available budget for the waste minimization assessment program and projects.

Worksheet 10 in Appendix A (Worksheet S6 in Appendix B) provides a means for evaluating waste stream priorities for the remainder of the assessment.

Small businesses, or large businesses with only a few waste generating operations should assess their entire facility. It is also beneficial to look at an entire facility when there are a large number of similar operations. Similarly, the implementation of good operating practices that involve procedural or organizational measures, such as soliciting employee suggestions, awareness-building programs, better inventory and maintenance procedures, and internal cost accounting changes, should be implemented on a facility-wide basis. Since many of these options do not require large capital expenditures, they should be implemented as soon as practical.

Selecting the Assessment Teams

The WM program task force is concerned with the whole plant. However, the focus of each of the assessment teams is more specific, concentrating on a particular waste stream or a particular area of the plant. Each team should include people with direct responsibility and knowledge of the particular waste stream or area of the plant. Table 3-4 presents four examples of teams for plants of various sizes in different industries.

In addition to the internal staff, consider using outside people, especially in the assessment and implementation phases. They may be trade association representatives, consultants, or experts from a different facility of the same company. In large multi-division companies, a centralized staff of experts at the corporate headquarters may be available. One or more "outsiders" can bring in new ideas and provide an objective viewpoint. An outsider also is more likely to counteract bias brought about by "inbreeding", or

Table 3-4. Examples of WM Assessment Teams

1. Metal finishing department in a large defense contractor.
   - Metal finishing department manager
   - Process engineer responsible for metal finishing processes
   - Facilities engineer responsible for metal finishing department*
   - Wastewater treatment department supervisor
   - Staff environmental engineer

2. Small pesticide formulator.
   - Production manager*
   - Environmental manager
   - Maintenance supervisor
   - Pesticide industry consultant

3. Cyanide plating operation at a military facility.
   - Internal assessment team
     - Environmental coordinator*
     - Environmental engineer
     - Electroplating facility engineering supervisor
     - Metallurgist
     - Materials science group chemist
   - Outside assessment team
     - Chemical engineers (2)
     - Environmental engineering consultant
     - Plating chemistry consultant

4. Large offset printing facility.
   - Internal assessment team
     - Plant vice president
     - Film processing supervisor
     - Pressroom supervisor
   - Outside assessment team
     - Chemical engineers (2)*
     - Environmental scientist
     - Printing industry technical consultant

* - Team leader

the "sacred cow" syndrome, such as when an old process area, rich in history, undergoes an assessment.

Outside consultants can bring a wide variety of experience and expertise to a waste minimization assessment. Consultants may be especially useful to smaller companies who may not have in-house expertise in the relevant waste minimization techniques and technologies.

Production operators and line employees must not be overlooked as a source of WM suggestions, since they possess firsthand knowledge and experience with the process. Their assistance is especially useful in assessing operational or procedural changes, or in equipment modifications that affect the way they do their work.

"Quality circles" have been instituted by many companies, particularly in manufacturing industries, to improve product quality and production efficiency. These quality circles consist of meetings of workers and supervisors, where improvements are proposed and evaluated. Quality circles are beneficial in that they involve the production people who are closely associated with the operations, and foster participation and commitment to improvement. Several large companies that have quality circles have used them as a means of soliciting successful suggestions for waste minimization.

Site Inspection

With a specific area or waste stream selected, and with the assessment team in place, the assessment continues with a visit to the site. In the case where the entire assessment team is employed at the plant being assessed, the team should have become very familiar with the specific area in the process of collecting the operating and design data. The members of the assessment team should familiarize themselves with the site as much as possible. Although the collected information is critical to gaining an understanding of the processes involved, seeing the site is important in order to witness the actual operation. For example, in many instances, a process unit is operated differently from the method originally described in the operating manual. Modifications may have been made to the equipment that were not recorded in the flow diagrams or equipment lists.

When people from outside of the plant participate in the assessment, it is recommended that a formal site inspection take place. Even when the team is made up entirely of plant employees, a site inspection by all team members is helpful after the site information has been collected and reviewed. The inspection helps to resolve questions or conflicting data uncovered during the review. The site inspection also provides additional information to supplement that obtained earlier.

When the assessment team includes members employed outside of the plant, the team should prepare a list of needed information and an inspection agenda. The list can be presented in the form of a checklist detailing objectives, questions and issues to be resolved, and/or further information requirements. The agenda and information list are given to the appropriate plant personnel in the areas to be assessed early enough before the visit to allow them to assemble the information in advance. Of course, it may be that the assessment team members themselves are in the best position to collect and compile much of the data. By carefully thinking out the agenda and needs list, important points are less likely to be overlooked during the inspection. Table 3-5 presents useful guidelines for the site inspection.

Table 3-5. Guidelines for the Site Inspection

- Prepare an agenda in advance that covers all points that still require clarification. Provide staff contacts in the area being assessed with the agenda several days before the inspection.
- Schedule the inspection to coincide with the particular operation that is of interest (e.g., make-up chemical addition, bath sampling, bath dumping, start-up, shutdown, etc.).
- Monitor the operation at different times during the shift, and if needed, during all three shifts, especially when waste generation is highly dependent on human involvement (e.g., in painting or parts cleaning operations).
- Interview the operators, shift supervisors, and foremen in the assessed area. Do not hesitate to question more than one person if an answer is not forthcoming. Assess the operators' and their supervisors' awareness of the waste generation aspects of the operation. Note their familiarity (or lack thereof) with the impacts their operation may have on other operations.
- Photograph the area of interest, if warranted. Photographs are valuable in the absence of plant layout drawings. Many details can be captured in photographs that otherwise could be forgotten or inaccurately recalled at a later date.
- Observe the "housekeeping" aspects of the operation. Check for signs of spills or leaks. Visit the maintenance shop and ask about any problems in keeping the equipment leak-free. Assess the overall cleanliness of the site. Pay attention to odors and fumes.
- Assess the organizational structure and level of coordination of environmental activities between various departments.
- Assess administrative controls, such as cost accounting procedures, material purchasing procedures, and waste collection procedures.

In performing the site inspection the assessment team should follow the process from the point where raw materials enter the area to the point where the products and the wastes leave the area. The team should identify the suspected sources of waste. This may include the production process; maintenance operations; storage areas for raw materials, finished product, and work-in-process. Recognize that the plant's waste treatment area itself may also offer opportunities to minimize waste. This inspection often results in forming preliminary conclusions about the causes of waste generation. Full confirmation of these conclusions may require additional data collection, analysis, and/or site visits.

Generating WM Options

Once the origins and causes of waste generation are understood, the assessment process enters the creative phase. The objective of this step is to generate a comprehensive set of WM options for further consideration. Following the collection of data and site inspections, the members of the team will have begun to identify possible ways to minimize waste in the assessed area. Identifying potential options relies both on the expertise and creativity of the team members. Much of the requisite knowledge may come from their education and on-the-job experience, however, the use of technical literature, contacts, and other sources is always helpful. Some sources of background information for waste minimization techniques are listed in Table 3-6.

Table 3-6. Sources of Background Information on WM Options

Trade associations
As part of their overall function to assist companies within their industry, trade associations generally provide assistance and information about environmental regulations and various available techniques for complying with these regulations. The information provided is especially valuable since it is industry-specific.

Plant engineers and operators
The employees that are intimately familiar with a facility's operations are often the best source of suggestions for potential WM options.

Published literature
Technical magazines, trade journals, government reports, and research briefs often contain information that can be used as waste minimization options.

State and local environmental agencies
A number of states and local agencies have, or are developing, programs that include technical assistance, information on industry-specific waste minimization techniques, and compiled bibliographies. Appendix E provides a list of addresses for state and federal programs for WM assistance.

Equipment vendors
Meetings with equipment vendors, as well as vendor literature, are particularly useful in identifying potential equipment-oriented options. Vendors are eager to assist companies in implementing projects. Remember, though, that the vendor's job is to sell equipment.

Consultants
Consultants can provide information about WM techniques. Section 2 discusses the use of consultants in WM programs. A consultant with waste minimization experience in your particular industry is most desirable.

Waste Minimization Options

The process for identifying options should follow a hierarchy in which source reduction options are explored first, followed by recycling options. This hierarchy of effort stems from the environmental desirability of source reduction as the preferred means of minimizing waste. Treatment options should be considered only after acceptable waste minimization techniques have been identified.

Recycling techniques allow hazardous materials to be put to a beneficial use. Source reduction techniques avoid the generation of hazardous wastes, thereby eliminating the problems associated with handling these wastes. Recycling techniques may be performed onsite or at an offsite facility designed to recycle the waste.

Source reduction techniques are characterized as good operating practices, technology changes, material changes, or product changes. Recycling techniques are characterized as use/reuse techniques and resource recovery techniques. These techniques are described below:

Source Reduction: Good Operating Practices

Good operating practices are procedural, administrative, or institutional measures that a company can use to minimize waste. Good operating practices apply to the human aspect of manufacturing operations. Many of these measures are used in industry largely as efficiency improvements and good management practices. Good operating practices can often be implemented with little cost and, therefore, have a high return on investment. These practices can be implemented in all areas of a plant, including production, maintenance operations, and in raw material and product storage. Good operating practices include the following:

- Waste minimization programs
- Management and personnel practices
- Material handling and inventory practices
- Loss prevention
- Waste segregation
- Cost accounting practices
- Production scheduling

Management and personnel practices include employee training, incentives and bonuses, and other programs that encourage employees to conscientiously strive to reduce waste. Material handling and inventory practices include programs to reduce loss of input materials due to mishandling, expired shelf life of time-sensitive materials, and proper storage conditions. Loss prevention minimizes wastes by avoiding leaks from equipment and spills. Waste segregation practices reduce the volume of hazardous wastes by preventing the mixing of hazardous and nonhazardous wastes. Cost accounting practices include programs to allocate waste treatment and disposal costs directly to the departments or groups that generate waste, rather than charging these costs to general company overhead accounts In doing so, the departments or groups that generate the waste become more aware of the effects of their treatment and disposal practices, and have a financial incentive to minimize their waste. By judicious scheduling of batch production runs, the frequency of equipment cleaning and the resulting waste can be reduced.

Example: Good Operating Practices

A large consumer product company in California adopted a corporate policy to minimize the generation of hazardous waste. In order to implement the policy, the company mobilized quality circles made up of employees representing areas within the plant that generated hazardous wastes. The company experienced a 75% reduction in the amount of wastes generated by instituting proper maintenance procedures suggested by the quality circle teams. Since the team members were also line supervisors and operators, they made sure the procedures were followed.

Source Reduction: Technology Changes

Technology changes are oriented toward process and equipment modifications to reduce waste, primarily in a production setting. Technology changes can range from minor changes that can be implemented in a matter of days at low cost, to the replacement of processes involving large capital costs. These changes include the following:

- Changes in the production process
- Equipment, layout, or piping changes
- Use of automation
- Changes in process operating conditions, such as
  - Flow rates
  - Temperatures
  - Pressures
  - Residence times

Example: Technology Changes

A manufacturer of fabricated metal products cleaned nickel and titanium wire in an alkaline chemical bath prior to using the wire in their product. In 1986, the company began to experiment with a mechanical abrasive system. The wire was passed through the system which uses silk and carbide pads and pressure to brighten the metal. The system worked, but required passing the wire through the unit twice for complete cleaning. In 1987. The company bought a second abrasive unit and installed it in series with the first unit. This system allowed the company to completely eliminate the need for the chemical cleaning bath.

Source Reduction: Input Material Changes

Input material changes accomplish waste minimization by reducing or eliminating the hazardous materials that enter the production process. Also, changes in input materials can be made to avoid the generation of hazardous wastes within the production processes. Input material changes include:

- Material purification
- Material substitution

Example: Input Material Changes

An electronic manufacturing facility of a large diversified corporation originally cleaned printed ciruit boards with solvents. The company found that by switching from a solvent-based cleaning system to an aqueous-based system that the same operating conditions and workloads could be maintained. The aqueous-based system was found to clean six times more effectively. This resulted in a lower product reject rate, and eliminated a hazardous waste.

Source Reduction: Product Changes

Product changes are performed by the manufacturer of a product with the intent of reducing waste resulting from a product's use. Product changes include:

- Product substitution
- Product conservation
- Changes in product composition

Example: Product changes

In the paint manufacturing industry, water-based coatings are finding increasing applications where solvent-based paints were used before. These products do not contain toxic or flammable solvents that make solvent-based paints hazardous when they are disposed of. Also, cleaning the applicators with solvent is not necessary. The use of water-

based paints instead of solvent-based paints also greatly reduces volatile organic compound emissions to the atmosphere.

Recycling: Use and Reuse

Recycling via use and/or reuse involves the return of a waste material either to the originating process as a substitute for an input material, or to another process as an input material.

Example: Reuse

A printer of newpaper advertising in California purchased an ink recycling unit to produce black newspaper ink from its various waste inks. The unit blends the different colors of waste ink together with fresh black ink and black toner to create the black ink. This ink is then filtered to remove flakes of dried ink. This ink is used in place of fresh black ink, and eliminates the need for the company to ship waste ink offsite for disposal. The price of the recycling unit was paid off in 18 months based only on the savings in fresh black ink purchases. The payback improved to 9 months when the costs for disposing of ink as a hazardous waste are included.

Recycling: Reclamation

Reclamation is the recovery of a valuable material from a hazardous waste. Reclamation techniques differ from use and reuse techniques in that the recovered material is not used in the facility, rather it is sold to another company.

Example: Reclamation

A photoprocessing company uses an electrolytic deposition cell to recover silver out of the rinsewater from film processing equipment. The silver is then sold to a small recycler. By removing the silver from this wastewater, the wastewater can be discharged to the sewer without additional pretreatment by the company. This unit pays for itself in less than two years with the value of silver recovered.

The company also collects used film and sells it to the same recycler. The recycler burns the film and collects the silver from the the residual ash. By removing the silver from the ash, the ash becomes nonhazardous.

Appendix E lists many WM techniques and concepts applicable to common waste-generating operations (coating, equipment cleaning, parts cleaning, and materials handling). Additionally, a list of good operating practices is provided.

Methods of Generating Options

The process by which waste minimization options are identified should occur in an environment that encourages creativity and independent thinking by the members of the assessment team. While the individual team members will suggest many potential options on their own, the process can be enhanced by using some of the common group decision techniques. These techniques allow the assessment team to identify options that the individual members might not have come up with on their own. Brainstorming sessions with the team members are an effective way of developing WM options. Most management or organizational behavior textbooks describe group decision techniques, such as brainstorming or the nominal group technique.

Worksheet 11 in Appendix A is a form for listing options that are proposed during an option generation session. Worksheet 12 in Appendix A is used to briefly describe and document the options that are proposed. Worksheets S7 and S8 in Appendix B perform the same function in the simplified set of worksheets.

Screening and Selecting Options for Further Study

Many waste minimization options will be identified in a successful assessment. At this point, it is necessary to identify those options that offer real potential to minimize waste and reduce costs. Since detailed evaluation of technical and economic feasibility is usually costly, the proposed options should be screened to identify those that deserve further evaluation. The screening procedure serves to eliminate suggested options that appear marginal, impractical, or inferior without a detailed and more costly feasibility study.

The screening procedures can range from an informal review and a decision made by the program manager or a vote of the team members, to quantitative decision-making tools. The informal evaluation is an unstructured procedure by which the assessment team or WM program task force selects the options that appear to be the best. This method is especially useful in small facilities, with small management groups, or in situations where only a few options have been generated. This method consists of a discussion and examination of each option.

The weighted sum method is a means of quantifying the important factors that affect waste management at a particular facility, and how each option will perform with respect to these factors. This method is recommended when there are a large number of options to consider. Appendix G presents the weighted sum method in greater detail, along with an example. Worksheet 13 in Appendix A is designed to screen and rank options using this method.

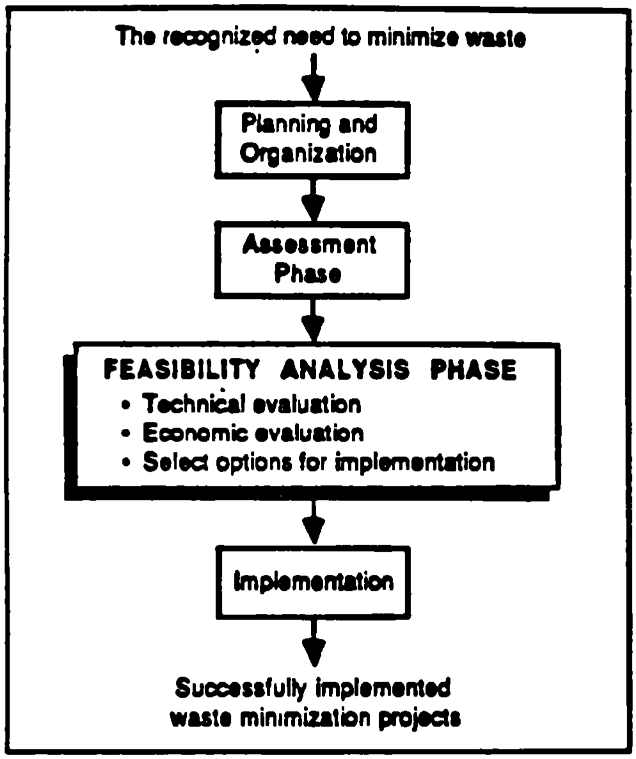
The assessment procedure is flexible enough to allow common group decision-making techniques to be used here. For example, many large corporations currently use decision-making systems that can be used to screen and rank WM options.

No matter what method is used, the screening procedure should consider the following questions.

- What is the main benefit gained by implementing this option? (e.g., economics, compliance, liability, workplace safety, etc.)
- Does the necessary technology exist to develop the option?
- How much does it cost? Is it cost effective?
- Can the option be implemented within a reasonable amount of time without disrupting production?
- Does the option have a good "track record"? If not, is there convincing evidence that the option will work as required?
- Does the option have a good chance of success? (A successfully initiated WM program will gain wider acceptance as the program progresses.)
- What other benefits will occur?

The results of the screening activity are used to promote the successful options for technical and economic feasibility analyses. The number of options chosen for the feasibility analyses depends on the time, budget, and resources available for such a study.

Some options (such as procedural changes) may involve no capital costs and can be implemented quickly with little or no further evaluation. The screening procedure should account for ease of implementation of an option. If such an option is clearly desirable and indicates a potential cost savings, it should be promoted for further study or outright implementation.



The final product of the assessment phase is a list of WM options for the assessed area. The assessment will have screened out the impractical or unattractive options. The next step is to determine if the remaining options are technically and economically feasible.

Technical Evaluation

The technical evaluation determines whether a proposed WM option will work in a specific application. The assessment team should use a "fast-track" approach in evaluating procedural changes that do not involve a significant capital expenditure. Process testing of materials can be done relatively quickly, if the options do not involve major equipment installation or modifications.

For equipment-related options or process changes, visits to see existing installations can be arranged through equipment vendors and industry contacts. The operator's comments are especially important and should be compared with the vendor's claims. Bench-scale or pilot-scale demonstration is often necessary. Often it is possible to obtain scale-up data using a rental test unit for bench-scale or pilot-scale experiments. Some vendors will install equipment on a trial basis, with acceptance and payment after a prescribed time, if the user is satisfied.

The technical evaluation of an option also must consider facility constraints and product requirements, such as those described in Table 4-1. Although an inability to meet these constraints may not present insurmountable problems, correcting them will likely add to the capital and/or operating costs.

Table 4-1. Typical Technical Evaluation Criteria

- Is the system safe for workers?
- Will product quality be maintained?
- Is space available?
- Is the new equipment, materials, or procedures compatible with production operating procedures, work flow, and production rates?
- Is additional labor required?
- Are utilities available? Or must they be installed, thereby raising capital costs?
- How long will production be stopped in order to install the system?
- Is special expertise required to operate or maintain the new system?
- Does the vendor provide acceptable service?
- Does the system create other environmental problems?

All affected groups in the facility should contribute to and review the results of the technical evaluation. Prior consultation and review with the affected groups (e.g., production, maintenance, purchasing) is needed to ensure the viability and acceptance of an option. If the option calls for a change in production methods or input materials, the project's effects on the quality of the final product must be determined. If after the technical evaluation, the project appears infeasible or impractical, it should be dropped. Worksheet 14 in Appendix A is a checklist of important items to consider when evaluating the technical feasibility of a WM option.

Economic Evaluation

The economic evaluation is carried out using standard measures of profitability, such as payback period, return on investment, and net present value. Each organization has its own economic criteria for selecting projects for implementation. In performing the economic evaluation, various costs and savings must be considered. As in any projects, the cost elements of a WM project can be broken down into capital costs and operating costs. The economic analysis described in this section and in the associated worksheets represents a preliminary, rather than detailed, analysis.

For smaller facilities with only a few processes, the entire WM assessment procedure will tend to be much

Table 4-2. Capital Investment for a Typical Large WM Project

Direct Capital Costs
- Site Development
  - Demolition and alteration work
  - Site clearing and grading
  - Walkways, roads, and fencing
- Process Equipment
  - All equipment listed on flow sheets
  - Spare parts
  - Taxes, freight, insurance, and duties
- Materials
  - Piping and ducting
  - Insulation and painting
  - Electrical
  - Instrumentation and controls
  - Buildings and structures
- Connections to Existing Utilities and Services (water, HVAC, power, steam, refrigeration, fuels, plant air and inert gas, lighting, and fire control)
- New Utility and Service Facilities (same items as above)
- Other Non-Process Equipment
- Construction/Installation
  - Construction/Installation labor salaries and burden
  - Supervision, accounting, timekeeping, purchasing, safety, and expediting
  - Temporary facilities
  - Construction tools and equipment
  - Taxes and insurance
  - Building permits, field tests, licenses

Indirect Capital Costs
- In-house engineering, procurement, and other home office costs
- Outside engineering, design, and consulting Services
- Permitting costs
- Contractors' fees
- Start-up costs
- Training costs
- Contingency
- Interest accrued during construction
  - TOTAL FIXED CAPITAL COSTS

Working Capital
- Raw materials inventory
- Finished product inventory
- Materials and supplies
  - TOTAL WORKING CAPITAL

TOTAL CAPITAL INVESTMENT

Source: Adapted from Perry, Chemical Engineer's Handbook (1985); and Peters and Timmerhaus, Plant Design and Economics for Chemical Engineers (1980).

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less formal. In this situation, several obvious WM options, such as installation of flow controls and good operating practices may be implemented with little or no economic evaluation. In these instances, no complicated analyses are necessary to demonstrate the advantages of adopting the selected WM options.

A proper perspective must be maintained between the magnitude of savings that a potential option may offer, and the amount of manpower required to do the technical and economic feasibility analyses.

Capital Costs

Table 4-2 is a comprehensive list of capital cost items associated with a large plant upgrading project. These costs include not only the fixed capital costs for designing, purchasing, and installing equipment, but also costs for working capital, permitting, training, start-up, and financing charges.

With the increasing level of environmental regulations, initial permitting costs are becoming a significant portion of capital costs for many recycling options (as well as treatment, storage, and disposal options). Many source reduction techniques have the advantage of not requiring environmental permitting in order to be implemented.

Operating Costs and Savings

The basic economic goal of any waste minimization project is to reduce (or eliminate) waste disposal costs and to reduce input material costs. However, a variety of other operating costs (and savings) should also be considered. In making the economic evaluation, it is convenient to use incremental operating costs in comparing the existing system with the new system that incorporates the waste minimization option. ("Incremental operating costs" represent the difference between the estimated operating costs associated with the WM option, and the actual operating costs of the existing system, without the option.) Table 4-3 describes incremental operating costs and savings and incremental revenues typically associated with waste minimization projects.

Reducing or avoiding present and future operating costs associated with waste treatment, storage, and disposal are major elements of the WM project economic evaluation. Companies have tended to ignore these costs in the past because land disposal was relatively inexpensive. However, recent regulatory requirements imposed on generators and waste management facilities have caused the costs of waste management to increase to the point where it is becoming a significant factor in a company's overall cost structure. Table 4-4 presents typical external costs for offsite waste treatment and disposal. In addition to these external costs, there are significant internal costs, including the labor to store and ship out wastes, liability insurance costs, and onsite treatment costs.

Table 4-3. Operating Costs and Savings Associated with WM Projects

Reduced waste management costs.
This includes reductions in costs for:
Offsite treatment, storage, and disposal fees
State fees and taxes on hazardous waste generators
Transportation costs
Onsite treatment, storage, and handling costs
Permitting, reporting, and recordkeeping costs

Input material cost savings.
An option that reduces waste usually decreases the demand for input materials.

Insurance and liability savings.
A WM option may be significant enough to reduce a company's insurance payments. It may also lower a company's potential liability associated with remedial clean-up of TSDFs and workplace safety. (The magnitude of liability savings is difficult to determine).

Changes in costs associated with quality.
A WM option may have a positive or negative effect on product quality. This could result in higher (or lower) costs for rework, scrap, or quality control functions.

Changes in utilities costs.
Utilities costs may increase or decrease. This includes steam, electricity, process and cooling water, plant air, refrigeration, or inert gas.

Changes in operating and maintenance labor, burden, and benefits.
An option may either increase or decrease labor requirements. This may be reflected in changes in overtime hours or in changes in the number of employees. When direct labor costs change, then the burden and benefit costs will also change. In large projects, supervision costs will also change.

Changes in operating and maintenance supplies.
An option may result increase or decrease the use of O&M supplies.

Changes in overhead costs.
Large WM projects may affect a facility's overhead costs.

Changes in revenues from increased (or decreased) production.
An option may result in an increase in the productivity of a unit. This will result in a change in revenues. (Note that operating costs may also change accordingly.)

Increased revenues from by-products.
A WM option may produce a by-product that can be sold to a recycler or sold to another company as a raw material. This will increase the company's revenues.

Table 4-4. Typical Costs of Offsite Industrial Waste Management*

Disposal	
Drummed hazardous waste**	
Solids	$75 to $110 per drum
Liquids	$65 to $120 per drum
Bulk waste	
Solids	$120 per cubic yard
Liquids	$0.60 to $2.30 per gallon
Lab packs	$110 per drum
Analysis (at disposal site)	$200 to $300
Transportation	$65 to $85 per hour @ 45 miles per hour (round trip)

* - Does not include internal costs, such as taxes and fees, and labor for manifest preparation, storage, handling, and recordkeeping.

** - Based on 55 gallon drums. These prices are for larger quantities of drummed wastes. Disposal of a small number of drums can be up to four times higher per drum.

For the purpose of evaluating a project to reduce waste quantities, some types of costs are larger and more easily quantified. These include:

- disposal fees
- transportation costs
- predisposal treatment costs
- raw materials costs
- operating and maintenance costs.

It is suggested that savings in these costs be taken into consideration first, because they have a greater effect on project economics and involve less effort to estimate reliably. The remaining elements are usually secondary in their direct impact and should be included on an as-needed basis in fine-tuning the analysis.

Profitability Analysis

A project's profitability is measured using the estimated net cash flows (cash incomes minus cash outlays) for each year of the project's life. A profitability analysis example in Appendix H includes two cash flow tables (Figure H-3 and H-4).

If the project has no significant capital costs, the project's profitability can be judged by whether an operating cost savings occurs or not. If such a project reduces overall operating costs, it should be implemented as soon as practical.

For projects with significant capital costs, a more detailed profitability analysis is necessary. The three standard profitability measures are:

- Payback period
- Internal rate of return (IRR)
- Net present value

The payback period for a project is the amount of time it takes to recover the initial cash outlay on the project. The formula for calculating the payback period on a pretax basis is the following:

$$\text{Payback period (in years)} = \frac{\text{Capital investment}}{\text{Annual operating cost savings}}$$

For example, suppose a waste generator installs a piece of equipment at a total cost of $120,000. If the piece of equipment is expected to save $48,000 per year, then the payback period is 2.5 years.

Payback periods are typically measured in years. However, a particularly attractive project may have a payback period measured in months. Payback periods in the range of three to four years are usually considered acceptable for low-risk investments. This method is recommended for quick assessments of profitability. If large capital expenditures are involved, it is usually followed by more detailed analysis.

The internal rate of return (IRR) and the net present value (NPV) are both discounted cash flow techniques for determining profitability. Many companies use these methods for ranking capital projects that are competing for funds. Capital funding for a project may well hinge on the ability of the project to generate positive cash flows beyond the payback period to realize acceptable return on investment. Both the NPV and IRR recognize the time value of money by discounting the projected future net cash flows to the present. For investments with a low level of risk, an aftertax IRR of 12 to 15 percent is typically acceptable.

Most of the popular spreadsheet programs for personal computers will automatically calculate IRR and NPV for a series of cash flows. Refer to any financial management, cost accounting, or engineering economics text for more information on determining the IRR or NPV. Appendix H presents a profitability analysis example for a WM project using IRR and NPV.

Adjustments for Risks and Liability

As mentioned earlier, waste minimization projects may reduce the magnitude of environmental and safety risks for a company. Although these risks can be identified, it is difficult to predict if problems occur, the nature of the problems, and their resulting magnitude. One way of accounting for the reduction of these risks is to ease the financial performance requirements of the project. For example, the acceptable payback may be lengthened from four to five years, or the required internal rate of return may be lowered from 15 percent to 12 percent. Such adjustments reflect recognition of elements that affect the risk exposure of the company, but cannot be included directly in the analyses. These adjustments are judgmental and necessarily reflect the individual viewpoints of the people evaluating the project for capital funding. Therefore, it is important that the financial analysts and the decision makers in the company be aware of the risk reduction and other benefits of the WM options. As a policy to encourage waste minimization, some companies have set lower hurdle rates for WM projects.

While the profitability is important in deciding whether or not to implement an option, environmental regulations may be even more important. A company operating in violation of environmental regulations can face fines, lawsuits, and criminal penalties for the company's managers. Ultimately, the facility may even be forced to shut down. In this case the total cash flow of a company can hinge upon implementing the environmental project.

Worksheets for Economic Evaluation

Worksheets 15 through 17 in Appendix A are used to determine the economic evaluation of a WM option. Worksheet 15 is a checklist of capital and operating cost items. Worksheet 16 is used to find a simple payback period for an option that requires capital investment. Worksheet 17 is used to find the net present value and internal rate of return for an option that requires capital investment. Worksheet S9 in Appendix B is used to record estimated capital and operating costs, and to determine the payback period in the simplified assessment procedure.

Final Report

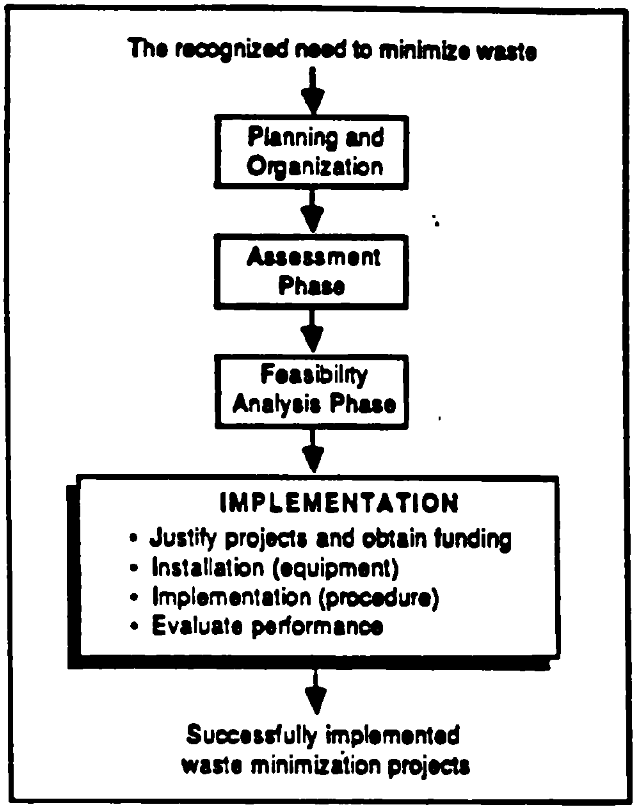
The product of a waste minimization assessment is a report that presents the results of the assessment and the technical and economic feasibility analyses. The report also containes recommendations to implement the feasible options.

A good final report can be an important tool for getting a project implemented. It is particularly valuable in obtaining funding for the project. In presenting the feasibility analyses, it is often useful to evaluate the project under different scenarios. For example, comparing a projects's profitability under optimistic and pessimistic assumptions (such as increasing waste disposal costs) can be beneficial. Sensitivity analyses that indicate the effect of key variables on profitability are also useful.

•The report should include not only how much the project will cost and its expected performance, but also how it will be done. It is important to discuss:

- whether the technology is established, with mention of succesful applications;
- the required resources and how they will be obtained;
- estimated construction period;
- estimated production downtime;
- how the performance of the project can be evaluated after it is implemented.

Before the report is finalized, it is important to review the results with the affected departments and to solicit their support. By having department representatives assist in preparing and reviewing the report, the chances are increased that the projects will be implemented. In summarizing the results, a qualitative evaluation of intangible costs and benefits to the company should be included. Reduced liabilities and improved image in the eyes of the employees and the community should be discussed.



The WM assessment report provides the basis for obtaining company funding of WM projects. Because projects are not always sold on their technical merits alone, a clear description of both tangible and intangible benefits can help edge a proposed project past competing projects for funding.

The champions of the WM assessment program should be flexible enough to develop alternatives or modifications. They should also be committed to the point of doing background and support work, and should anticipated potential problems in implementing the options. Above all, they should keep in mind that an idea will not sell if the sponsors are not sold on it themselves.

Obtaining Funding

Waste reduction projects generally involve improvements in process efficiency and/or reductions in operating costs of waste management. However, an organization's capital resources may be prioritized toward enhancing future revenues (for example, moving into new lines of business, expanding plant capacity, or acquiring other companies), rather than toward cutting current costs. If this is the case, then a sound waste reduction project could be postponed until the next capital budgeting period. It is then up to the project sponsor to ensure that the project is reconsidered at that time.

Knowing the level within the organization that has approval authority for capital projects will help in enlisting the appropriate support. In large corporations, smaller projects are typically approved at the plant manager level, medium-size projects at the divisional vice president level, and larger projects at the executive committee level.

An evaluation team made up of financial and technical personnel can ensure that a sponsor's enthusiasm is balanced with objectivity. It can also serve to quell opposing "can't be done" or "if it ain't broke, don't fix it" attitudes that might be encountered within the organization. The team should review the project in the context of:

- past experience in this area of operation
- what the market and the competition are doing
- how the implementation program fits into the company's overall business strategy
- advantages of the proposal in relation to competing requests for capital funding

Even when a project promises a high interal rate of return, some companies will have difficulty raising funds internally for capital investment. In this case, the company should look to outside financing. The company generally has two major sources to consider: private sector financing and government-assisted funding.

Private sector financing includes bank loans and other conventional sources of financing. Government financing is available in some cases. It may be worthwhile to contact your state's Department of Commerce or the federal Small Business Administration for information regarding loans for pollution control or hazardous waste disposal projects. Some states can provide technical and financial assistance. Appendix F includes a list of states providing this assistance and addresses to get information.

Installation

Waste minimization options that involve operational, procedural, or materials changes (without additions or modifications to equipment) should be implemented as soon as the potential cost savings have been determined. For projects involving equipment modifications or new equipment, the installation of a waste minimization project is essentially no different from any other capital improvement project. The phases of the project include planning, design, procurement, and construction.

Worksheet 18 is a form for documenting the progress of a WM project through the implementation phase.

Demonstration and Follow-up

After the waste minimization option has been implemented, it remains to be seen how effective the option actually turns out to be. Options that don't measure up to their original performance expectations may requre rework or modifications. It is important to get warranties from vendors prior to installation of the equipment.

The documentation provided through a follow-up evaluation represents an important source of information for future uses of the option in other facilities. Worksheet 19 is a form for evaluating the performance of an implemented WM option. The experience gained in implementing an option at one facility can be used to reduce the problems and costs of implementing options at subsequent facilities.

Measuring Waste Reduction

One measure of effectiveness for a WM project is the project's effect on the organization's cash flow. The project should pay for itself through reduced waste management costs and reduced raw materials costs. However, it is also important to measure the actual reduction of waste accomplished by the WM project.

The easiest way to measure waste reduction is by recording the quantities of waste generated before and after a WM project has been implemented. The difference, dividied by the original waste generation rate, represents the percentage reduction in waste quantity. However, this simple measurement ignores other factors that also affect the quantity of waste generated.

In general, waste generation is directly dependent on the production rate. Therefore, the ratio of waste generation rate to production rate is a convenient way of measuring waste reduction.

Expressing waste reduction in terms of the ratio of waste to production rates is not free of problems, however. One of these problems is the danger of using the ratio of infrequent large quantities to the production rate. This problem is illustrated by a situation where a plant undergoes a major overhaul involving equipment cleaning, paint stripping, and repainting. Such overhauls are fairly infrequent and are typically performed every three to five years. The decision to include this intermittent stream in the calculation of the waste reduction index, based on the ratio of waste rate to product rate, would lead to an increase in this index. This decision cannot be justified, however, since the infrequent generation of painting wastes is not a function of production rate. In a situation like this, the waste reduction progress should be measured in terms of the ratio of waste quantity or materials use to the square footage of the area painted. In general, a distinction should be made between production- related wastes and maintenance-related wastes and clean-up wastes.

Also, a few waste streams may be inversely proportional to production rate. For example, a waste resulting from outdated input materials is likely to increase if the production rate decreases. This is because the age-dated materials in inventory are more likely to expire when their use in production decreases.

For these reasons, care must be taken when expressing the extent of waste reduction. This requires that the means by which wastes are generated be well understood.

In measuring waste reduction, the total quantity of an individual waste stream should be measured, as well as the individual waste components or characteristics. Many companies have reported substantial reduction in the quanitites of waste disposed. Often, much of the reduction can be traced to good housekeeping and steps taken to concentrate a dilute aqueous waste. Although concentration, as such, does not fall within the definition of waste minimization, there are practical benefits that result from concentrating wastewater streams, including decreased disposal costs. Concentration may render a waste stream easier to recycle, and is also desirable if a facility's current wastewater treatment system is overloaded.

Obtaining good quality data for waste stream quanities, flows, and composition can be costly and time consuming. For this reason, it may be practical, in some instances, to express waste reduction indirectly in terms of the ratio of input materials consumption to production rate. These data are easier to obtain, although the measure is not direct.

Measuring waste minimization by using a ratio of waste quantity to material throughput or product output is generally more meaningful for specific units or operations, rather than for an entire facility. Therefore, it is important to preserve the focus of the WM project when measuring and reporting progress. For those operations not involving chemical reactions, it may be helpful to measure WM progress by using the ratio of input material quantity to material throughput or production rate.

Waste Minimization Assessments for New Production Processes

This manual concentrates on waste minimization assessments conducted in existing facilities. However, it is important that waste minimization principles be applied to new projects. In general, it is easier to avoid waste generation during the research and development or design phase than to go back and modify the process after it has already been installed.

The planning and design team for a new product, production process, or operation should address waste generation aspects early on. The assessment procedure in this manual can be modified to provide a WM review of a product or process in the planning or design phase. The earlier the assessment is performed, the less likely it is that the project will require expensive changes. All new projects should be reviewed by the waste minimization program task force.

A better approach than a pre-project assessment is to include one or more members of the WM program task force on any new project that will generate waste. In this way, the new project will benefit from the "built-in" presence of a WM champion and his or her influence to design the process to minimize waste. At a California facility of a major defense contractor, all new projects and modifications to existing facilities and equipment are reviewed by the WM program team. All projects that have no environmental impact are quickly screened and approved. Those projects that do have an environmental impact are assigned to a team member who participates in the project kick-off and review meetings from inception to implementation.

Ongoing Waste Minimization Program

The WM program is a continuing, rather than a one-time effort. Once the highest priority waste streams and facility areas have been assessed and those projects have been implemented, the assessment program should look to areas and waste streams with lower priorities. The ultimate goal of the WM program should be to reduce the generation of waste to the maximum extent achievable. Companies that have eliminated the generation of hazardous waste should continue to look at reducing industrial wastewater discharges, air emissions, and solid wastes.

The frequency with which assessments are done will depend on the program's budget, the company's budgeting cycle (annual cycle in most companies), and special circumstances. These special circumstances might be:

- a change in raw material or product requirements
- higher waste management costs
- new regulations
- new technology
- a major event with undesirable environmental consequences (such as a major spill)

Aside from the special circumstances, a new series of assessments should be conducted each fiscal year.

To be truly effective, a philosophy of waste minimization must be developed in the organization. This means that waste minimization must be an integral part of the company's operations. The most successful waste minimization programs to date have all developed this philosophy within their companies.

Appendix A
Waste Minimization Assessment Worksheets

The worksheets that follow are designed to facilitate the WM assessment procedure. Table A-1 lists the worksheets, according to the particular phase of the program, and a brief description of the purpose of the worksheets. Appendix B presents a series of simplified worksheets for small businesses or for preliminary assessments.

Table A-1. List of Waste Minimization Assessment Worksheets

Phase	Number and Title	Purpose/Remarks
	1. Assessment Overview	Summarizes the overall assessment procedure.
Planning and Organization (Section 2)		
	2. Program Organization	Records key members in the WMA program task force and the WM assessment teams. Also records the relevant organization.
	3. Assessment Team Make-up	Lists names of assessment team members as well as duties. Includes a list of potential departments to consider when selecting the teams.
Assessment Phase (Section 3)		
	4. Site Description	Lists background information about the facility, including location, products, and operations.
	5. Personnel	Records information about the personnel who work in the area to be assessed.
	6. Process Information	This is a checklist of useful process information to look for before starting the assessment.
	7. Input Materials Summary	Records input material information for a specific production or process area. This includes name, supplier, hazardous component or properties, cost, delivery and shelf-life information, and possible substitutes.
	8. Products Summary	Identifies hazardous components, production rate, revenues, and other information about products.
	9. Individual Waste Stream Characterization	Records source, hazard, generation rate, disposal cost, and method of treatment or disposal for each waste stream.
	10. Waste Stream Summary	Summarizes all of the information collected for each waste stream. This sheet is also used to prioritize waste streams to assess.

(continued)

Table A-1. List of Waste Minimization Assessment Worksheets (continued)

Phase	Number and Title	Purpose/Remarks
Assessment Phase (continued) (Section 3)		
	11. Option Generation	Records options proposed during brainstorming or nominal group technique sessions. Includes the rationale for proposing each option.
	12. Option Description	Describes and summarizes information about a proposed option. Also notes approval of promising options.
	13. Options Evaluation by Weighted Sum Method	Used for screening options using the weighted sum method.
Feasibility Analysis Phase (Section 4)		
	14. Technical Feasibility	Detailed checklist for performing a technical evaluation of a WM option. This worksheet is divided into sections for equipment-related options, personnel/procedural-related options, and materials-related options.
	15. Cost Information	Detailed list of capital and operating cost information for use in the economic evaluation of an option.
	16. Profitability Worksheet #1 Payback Period	Based on the capital and operating cost information developed from Worksheet 15, this worksheet is used to calculate the payback period.
	17. Profitability Worksheet #2 Cash Flow for NPV and IRR	This worksheet is used to develop cash flows for calculating NPV or IRR.
Implementation (Section 5)		
	18. Project Summary	Summarizes important tasks to be performed during the implementation of an option. This includes deliverable, responsible person, budget, and schedule.
	19. Option Performance	Records material balance information for evaluating the performance of an implemented option.

Firm ______	Waste Minimization Assessment Worksheets	Prepared By ______
Site ______		Checked By ______
Date ______	Proj. No. ______	Sheet 1 of 1 Page ___ of ___

WORKSHEET 1

ASSESSMENT OVERVIEW

EPA

Begin the Waste Minimization Assessment Program

↓

PLANNING AND ORGANIZATION

	Worksheets used
• Get management commitment	
• Set overall assessment program goals	
• Organize assessment program task force	2

↓ Assessment organization and commitment to proceed

ASSESSMENT PHASE

	Worksheets used
• Compile process and facility data	4,6,7,8,9,10
• Prioritize and select assessment targets	10
• Select people for assessment teams	3
• Review data and inspect site	
• Generate options	11,12
• Screen and select options for further study	13

↓ Assessment report of selected options

FEASIBILITY ANALYSIS PHASE

	Worksheets used
• Technical evaluation	14
• Economic evaluation	15,16,17
• Select options for implementation	

↓ Final report, including recommended options

IMPLEMENTATION

	Worksheets used
• Justify projects and obtain funding	
• Installation (equipment)	18
• Implementation (procedure)	18
• Evaluate performance	19

↓

Successfully operating waste minimization projects

Repeat the process → Select new assessment targets and reevaluate previous options → ASSESSMENT PHASE

Firm ________	Waste Minimization Assessment	Prepared By ________
Site ________		Checked By ________
Date ________	Proj. No. ________	Sheet 1 of 1 Page __ of __

WORKSHEET 2

PROGRAM ORGANIZATION

EPA

FUNCTION	NAME	LOCATION	TELEPHONE #
Program Manager			
Site Coordinator			
Assessment Team Leader			

Organization Chart

(sketch)

Firm ______ Site ______ Date ______	**Waste Minimization Assessment** Proj. No. ______	Prepared By ______ Checked By ______ Sheet 1 of 1 Page __ of __

WORKSHEET 3

ASSESSMENT TEAM MAKE-UP

EPA

Function/Department	Name	Location/ Telephone #	Manhours Required	Duties		
				Lead	Support	Review
Assessment Team						
Leader						
Site Coordinator						
Operations						
Engineering						
Maintenance						
Scheduling						
Materials Control						
Procurement						
Shipping/Receiving						
Facilities						
Quality Control						
Environmental						
Accounting						
Personnel						
R & D						
Legal						
Management						
Contractor/Consultant						
Safety						

Firm ____	Waste Minimization Assessment	Prepared By ____
Site ____		Checked By ____
Date ____	Proj. No. ____	Sheet 1 of 1 Page __ of __

WORKSHEET 4

SITE DESCRIPTION

EPA

Firm:

Plant:

Department:

Area:

Street Address:

City:

State/ZIP Code:

Telephone: (   )

Major Products:

SIC Codes:

EPA Generator Number :

Major Unit or:

Product or:

Operations:

Facilities/Equipment Age:

Firm ____	Waste Minimization Assessment	Prepared By ____
Site ____		Checked By ____
Date ____	Proj. No. ____	Sheet 1 of 1 Page __ of __

WORKSHEET 5

PERSONNEL

EPA

Attribute	Overall	Department/Area			
Total Staff					
Direct Supv. Staff					
Management					
Average Age, yrs.					
Annual Turnover Rate %					
Seniority, yrs.					
Yrs. of Formal Education					
Training, hrs./yr.					
Additional Remarks					

Firm ______	Waste Minimization Assessment	Prepared By ______
Site ______		Checked By ______
Date ______	Proj. No. ______	Sheet 1 of 1 Page __ of __

WORKSHEET 6

PROCESS INFORMATION

EPA

Process Unit/Operation: ______

Operation Type: ☐ Continuous ☐ Discrete ☐ Batch or Semi-Batch ☐ Other ______

Document	Status					
	Complete? (Y/N)	Current? (Y/N)	Last Revision	Used in this Report (Y/N)	Document Number	Location
Process Flow Diagram						
Material/Energy Balance						
Design						
Operating						
Flow/Amount Measurements						
Stream						
Analyses/Assays						
Stream						
Process Description						
Operating Manuals						
Equipment List						
Equipment Specifications						
Piping & Instrument Diagrams						
Plot and Elevation Plan(s)						
Work Flow Diagrams						
Hazardous Waste Manifests						
Emission Inventories						
Annual/Biennial Reports						
Environmental Audit Reports						
Permit/Permit Applications						
Batch Sheet(s)						
Materials Application Diagrams						
Product Composition Sheets						
Material Safety Data Sheets						
Inventory Records						
Operator Logs						
Production Schedules						

Firm ____	Waste Minimization Assessment	Prepared By ____
Site ____		Checked By ____
Date ____	Proj. No. ____	Sheet 1 of 1 Page __ of __

WORKSHEET 7

INPUT MATERIALS SUMMARY

EPA

Attribute	Description[1]		
	Stream No.____	Stream No.____	Stream No.____
Name/ID			
Source/Supplier			
Component/Attribute of Concern			
Annual Consumption Rate			
Overall			
Component(s) of Concern			
Purchase Price, $ per ______			
Overall Annual Cost			
Delivery Mode[2]			
Shipping Container Size & Type[3]			
Storage Mode[4]			
Transfer Mode[5]			
Empty Container Disposal/Management[6]			
Shelf Life			
Supplier Would			
- accept expired material (Y/N)			
- accept shipping containers (Y/N)			
- revise expiration date (Y/N)			
Acceptable Substitute(s), if any			
Alternate Supplier(s)			

1 stream numbers, if applicable, should correspond to those used on process flow diagrams.
2 e.g., pipeline, tank car, 100 bbl. tank truck, truck, etc.
3 e.g., 55 gal. drum, 100 lb. paper bag, tank, etc.
4 e.g., outdoor, warehouse, underground, aboveground, etc.
5 e.g., pump, forklift, pneumatic transport, conveyor, etc.
6 e.g., crush and landfill, clean and recycle, return to supplier, etc.

Firm ______	Waste Minimization Assessment	Prepared By ______
Site ______		Checked By ______
Date ______	Proj. No. ______	Sheet 1 of 1 Page __ of __

WORKSHEET 8

PRODUCTS SUMMARY

EPA

Attribute	Description[1]		
	Stream No.____	Stream No.____	Stream No.____
Name/ID			
Component/Attribute of Concern			
Annual Production Rate			
Overall			
Component(s) of Concern			
Annual Revenues, $ ______			
Shipping Mode			
Shipping Container Size & Type			
Onsite Storage Mode			
Containers Returnable (Y/N)			
Shelf Life			
Rework Possible (Y/N)			
Customer Would			
• relax specification (Y/N)			
• accept larger containers (Y/N)			

[1] stream numbers, if applicable, should correspond to those used on process flow diagrams.

Firm ______	Waste Minimization Assessment	Prepared By ______
Site ______		Checked By ______
Date ______	Proj. No. ______	Sheet 2 of 4 Page __ of __

WORKSHEET 9a

INDIVIDUAL WASTE STREAM CHARACTERIZATION

EPA

1. Waste Stream Name/ID: ______ Stream Number ______
   Process Unit/Operation ______

2. Waste Characteristics (attach additional sheets with composition data, as necessary.)

   ☐ gas ☐ liquid ☐ solid ☐ mixed phase

   Density, lb/cuft ______ High Heating Value, Btu/lb ______
   Viscosity/Consistency ______
   pH ______ ,Flash Point ______ ; % Water ______

3. Waste Leaves Process as:
   ☐ air emission ☐ waste water ☐ solid waste ☐ hazardous waste

4. Occurrence
   ☐ continuous ______
   ☐ discrete ______
   discharge triggered by ☐ chemical analysis ______
   ☐ other (describe) ______
   Type: ☐ periodic ______ length of period: ______
   ☐ sporadic (irregular occurrence)
   ☐ non-recurrent

5. Generation Rate
   Annual ______ lbs per year
   Maximum ______ lbs per ______
   Average ______ lbs per ______
   Frequency ______ batches per ______
   Batch Size ______ average ______ range

Firm ______	Waste Minimization Assessment	Prepared By ______
Site ______	Proc. Unit/Oper. ______	Checked By ______
Date ______	Proj. No. ______	Sheet 2 of 4 Page __ of __

WORKSHEET 9b

INDIVIDUAL WASTE STREAM CHARACTERIZATION

(continued)

EPA

6. Waste Origins/Sources

Fill out this worksheet to identify the origin of the waste. If the waste is a mixture of waste streams, fill out a sheet for each of the individual waste streams.

Is the waste mixed with other wastes? ☐ Yes ☐ No

Describe how the waste is generated.

____

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Example: Formation and removal of an undesirable compound, removal of an unconverted input material, depletion of a key component (e.g., drag-out), equipment cleaning waste, obsolete input material, spoiled batch and production run, spill or leak cleanup, evaporative loss, breathing or venting losses, etc.

Firm ______	**Waste Minimization Assessment**	Prepared By ______
Site ______	Proc. Unit/Oper. ______	Checked By ______
Date ______	Proj. No. ______	Sheet 3 of 4 Page __ of __

WORKSHEET **9c**

INDIVIDUAL WASTE STREAM CHARACTERIZATION

(continued)

EPA

Waste Stream ______

7. Management Method

Leaves site in
- ☐ bulk ______
- ☐ roll off bins ______
- ☐ 55 gal drums ______
- ☐ other (describe) ______

Disposal Frequency ______

Applicable Regulations[1] ______

Regulatory Classification[2] ______

Managed
- ☐ onsite ☐ offsite
- ☐ commercial TSDF ______
- ☐ own TSDF ______
- ☐ other (describe) ______

Recycling
- ☐ direct use/re-use ______
- ☐ energy recovery ______
- ☐ redistilled ______
- ☐ other (describe) ______

reclaimed material returned to site?

☐ Yes ☐ No ☐ used by others

residue yield ______

residue disposal/repository ______

Note[1] list federal, state & local regulations, (e.g., RCRA, TSCA, etc.)

Note[2] list pertinent regulatory classification (e.g., RCRA - Listed K011 waste, etc.)

Firm ______	Waste Minimization Assessment	Prepared By ______
Site ______	Proc. Unit/Oper. ______	Checked By ______
Date ______	Proj. No. ______	Sheet 4 of 4 Page __ of __

WORKSHEET 9d

INDIVIDUAL WASTE STREAM CHARACTERIZATION

(continued)

EPA

Waste Stream ______

7. Management Method (continued)

Treatment

- ☐ biological ______
- ☐ oxidation/reduction ______
- ☐ incineration ______
- ☐ pH adjustment ______
- ☐ precipitation ______
- ☐ solidification ______
- ☐ other (describe) ______

residue disposal/repository ______

Final Disposition

- ☐ landfill ______
- ☐ pond ______
- ☐ lagoon ______
- ☐ deep well ______
- ☐ ocean ______
- ☐ other (describe) ______

Costs as of ______ (quarter and year)

Cost Element:	Unit Price $ per ___	Reference/Source:
Onsite Storage & Handling		
Pretreatment		
Container		
Transportation Fee		
Disposal Fee		
Local Taxes		
State Tax		
Federal Tax		
Total Disposal Cost		

Firm ____	Waste Minimization Assessment	Prepared By ____
Site ____	Proc. Unit/Oper. ____	Checked By ____
Date ____	Proj. No. ____	Sheet 1 of 1 Page __ of __

WORKSHEET 10

WASTE STREAM SUMMARY

EPA

Attribute		Description[1]					
		Stream No. ____		Stream No. ____		Stream No. ____	
Waste ID/Name:							
Source/Origin							
Component/or Property of Concern							
Annual Generation Rate (units ________)							
Overall							
Component(s) of Concern							
Cost of Disposal							
Unit Cost ($ per: ________)							
Overall (per year)							
Method of Management[2]							
Priority Rating Criteria[3]	Relative Wt. (W)	Rating (R)	R x W	Rating (R)	R x W	Rating (R)	R x W
Regulatory Compliance							
Treatment/Disposal Cost							
Potential Liability							
Waste Quantity Generated							
Waste Hazard							
Safety Hazard							
Minimization Potential							
Potential to Remove Bottleneck							
Potential By-product Recovery							
Sum of Priority Rating Scores		Σ(R x W)		Σ(R x W)		Σ(R x W)	
Priority Rank							

Notes:
1. Stream numbers, if applicable, should correspond to those used on process flow diagrams.
2. For example, sanitary landfill, hazardous waste landfill, onsite recycle, incineration, combustion with heat recovery, distillation, dewatering, etc.
3. Rate each stream in each category on a scale from 0 (none) to 10 (high).

Firm ______	**Waste Minimization Assessment**	Prepared By ______
Site ______	Proc. Unit/Oper. ______	Checked By ______
Date ______	Proj. No. ______	Sheet 1 of 1 Page __ of __

WORKSHEET 11

OPTION GENERATION

EPA

Meeting format (e.g., brainstorming, nominal group technique) ______

Meeting Coordinator ______

Meeting Participants ______

List Suggested Options	Rationale/Remarks on Option

Firm ____	Waste Minimization Assessment	Prepared By ____
Site ____	Proc. Unit/Oper. ____	Checked By ____
Date ____	Proj. No. ____	Sheet 1 of 1 Page __ of __

WORKSHEET 12

OPTION DESCRIPTION

EPA

Option Name: ____________________

Briefly describe the option ____________________

____

____

____

____

____

____

____

Waste Stream(s) Affected: ____________________

____

Input Material(s) Affected: ____________________

____

Product(s) Affected: ____________________

____

Indicate Type:

☐ **Source Reduction**

- ___ **Equipment-Related Change**
- ___ **Personnel/Procedure-Related Change**
- ___ **Materials-Related Change**

☐ **Recycling/Reuse**

___	**Onsite**	___	**Material reused for original purpose**
___	**Offsite**	___	**Material used for a lower-quality purpose**
		___	**Material sold**
		___	**Material burned for heat recovery**

Originally proposed by: ____________________ **Date:** ____________

Reviewed by: ____________________ **Date:** ____________

Approved for study? ______ **yes** ______ **no, by:** ____________________

Reason for Acceptance or Rejection ____________________

Firm ______	Waste Minimization Assessment	Prepared By ______
Site ______	Proc. Unit/Oper. ______	Checked By ______
Date ______	Proj. No. ______	Sheet 1 of 1 Page 1 of 1

WORKSHEET 13

OPTIONS EVALUATION BY WEIGHTED SUM METHOD

EPA

Criteria	Weight (W)	Options Rating (R)									
		#1 Option ______		#2 Option ______		#3 Option ______		#4 Option ______		#5 Option ______	
		R	R x W	R	R x W	R	R x W	R	R x W	R	R x W
Reduction in waste's hazard											
Reduction of treatment/disposal costs											
Reduction of safety hazards											
Reduction of input material costs											
Extent of current use in industry											
Effect on product quality (no effect = 10)											
Low capital cost											
Low O & M cost											
Short implementation period											
Ease of implementation											
Final Evaluation	Sum of Weighted Ratings Σ (W x R)										
	Option Ranking										
Feasibility Analysis Scheduled for (Date)											

Firm ______	Waste Minimization Assessment	Prepared By ______
Site ______	Proc. Unit/Oper. ______	Checked By ______
Date ______	Proj. No. ______	Sheet 1 of 6 Page __ of __

WORKSHEET 14a

TECHNICAL FEASIBILITY

EPA

WM Option Description ______

1. Nature of WM Option
   - ☐ Equipment-Related
   - ☐ Personnel/Procedure-Related
   - ☐ Materials-Related

2. If the option appears technically feasible, state your rationale for this. ______

   Is further analysis required? ☐ Yes ☐ No. If yes, continue with this worksheet. If not, skip to worksheet 15.

3. Equipment - Related Option

	YES	NO	
Equipment available commercially?	☐	☐	______
Demonstrated commercially?	☐	☐	______
In similar application?	☐	☐	______
Successfully?	☐	☐	______

Describe closest industrial analog ______

Describe status of development ______

Prospective Vendor	Working Installation(s)	Contact Person(s)	Date Contacted 1.

1. Also attach filled out phone conversation notes, installation visit report, etc.

Firm ____	Waste Minimization Assessment	Prepared By ____
Site ____	Proc. Unit/Oper. ____	Checked By ____
Date ____	Proj. No. ____	Sheet 2 of 6 Page __ of __

WORKSHEET 14b

TECHNICAL FEASIBILITY

(continued)

EPA

WM Option Description ____

3. Equipment-Related Option (continued)

Performance information required (describe parameters): ____

Scaleup information required (describe): ____

Testing Required: ☐ yes ☐ no

Scale: ☐ bench ☐ pilot ☐ ____

Test unit available? ☐ yes ☐ no ____

Test Parameters (list) ____

Number of test runs: ____

Amount of material(s) required: ____

Testing to be conducted: ☐ in-plant ☐ ____

Facility/Product Constraints:

Space Requirements ____

Possible locations within facility ____

Firm ______	Waste Minimization Assessment	Prepared By ______
Site ______	Proc. Unit/Oper. ______	Checked By ______
ate ______	Proj. No. ______	Sheet 3 of 6 Page __ of __

WORKSHEET 14c

TECHNICAL FEASIBILITY

(continued)

EPA

WM Option Description ______

2. Equipment-Related Option (continued)

Utility Requirements:

Electric Power — Volts (AC or DC) ______ kW ______

Process Water — Flow ______ Pressure ______

Quality (tap, demin, etc.) ______

Cooling Water — Flow ______ Pressure ______

Temp. In ______ Temp. Out ______

Coolant/Heat Transfer Fluid ______

Temp. In ______ Temp. Out ______

Duty ______

Steam — Pressure ______ Temp. ______

Duty ______ Flow ______

Fuel — Type ______ Flow ______

Duty ______

Plant Air ______ Flow ______

Inert Gas ______ Flow ______

Estimated delivery time (after award of contract) ______

Estimated installation time ______

Installation dates ______

Estimated production downtime ______

Will production be otherwise affected? Explain the effect and impact on production. ______

______

______

______

Will product quality be affected? Explain the effect on quality. ______

______

______

______

Firm ______	Waste Minimization Assessment	Prepared By ______
Site ______	Proc. Unit/Oper. ______	Checked By ______
Date ______	Proj. No. ______	Sheet 4 of 6 Page __ of __

WORKSHEET 14d

TECHNICAL FEASIBILITY

(continued)

EPA

WM Option Description ______

3. Equipment-Related Option (continued)

Will modifications to work flow or production procedures be required? Explain. ______

______

______

______

______

Operator and maintenance training requirements

Number of people to be trained ______ ☐ Onsite

______ ☐ Offsite

Duration of training

Describe catalyst, chemicals, replacement parts, or other supplies required.

Item	Rate or Frequency of Replacement	Supplier, Address

Does the option meet government and company safety and health requirements?

☐ Yes ☐ No Explain ______

______

______

How is service handled (maintenance and technical assistance)? Explain ______

______

______

______

What warranties are offered? ______

______

______

WORKSHEET 14e

TECHNICAL FEASIBILITY

(continued)

EPA

WM Option Description ______

3. Equipment-Related Option (continued)

Describe any additional storage or material handling requirements. ______

Describe any additional laboratory or analytical requirements. ______

4. Personnel/Procedure-Related Changes

Affected Departments/Areas ______

Training Requirements ______

Operating Instruction Changes. Describe responsible departments. ______

5. Materials-Related Changes (Note: If substantial changes in equipment are required, then handle the option as an equipment-related one.)

	Yes	No
Has the new material been demonstrated commercially?	☐	☐
In a similar application?	☐	☐
Successfully?	☐	☐

Describe closest application. ______

Firm ______	Waste Minimization Assessment	Prepared By ______
Site ______	Proc. Unit/Oper. ______	Checked By ______
Date ______	Proj. No. ______	Sheet 6 of 6 Page __ of __

WORKSHEET 14f

TECHNICAL FEASIBILITY

(continued)

EPA

WM Option Description ______

4. Materials-Related Changes (continued)

Affected Departments/Areas ______

Will production be affected? Explain the effect and impact on production.

Will product quality be affected? Explain the effect and the impact on product quality.

Will additional storage, handling or other ancillary equipment be required? Explain.

Describe any training or procedure changes that are required.

Decribe any material testing program that will be required.

Firm ____	Waste Minimization Assessment	Prepared By ____
Site ____	Proc. Unit/Oper. ____	Checked By ____
Date ____	Proj. No. ____	Sheet 1 of 6 Page __ of __

WORKSHEET 15a

COST INFORMATION

EPA

WM Option Description ____

CAPITAL COSTS - Include all costs as appropriate. **TOTALS**

☐ **Purchased Process Equipment**
- Price (fob factory) ____
- Taxes, freight, insurance ____
- Delivered equipment cost ____
- Price for Initial Spare Parts Inventory ____ ____

☐ **Estimated Materials Cost**
- Piping ____
- Electrical ____
- Instruments ____
- Structural ____
- Insulation/Piping ____ ____

☐ **Estimated Costs for Utility Connections and New Utility Systems**
- Electricity ____
- Steam ____
- Cooling Water ____
- Process Water ____
- Refrigeration ____
- Fuel (Gas or Oil) ____
- Plant Air ____
- Inert Gas ____ ____

☐ **Estimated Costs for Additional Equipment**
- Storage & Material Handling ____
- Laboratory/Analytical ____
- Other ____ ____

☐ **Site Preparation** ____
(Demolition, site clearing, etc.) ____

☐ **Estimated Installation Costs**
- Vendor ____
- Contractor ____
- In-house Staff ____ ____

Firm ______	Waste Minimization Assessment	Prepared By ______
Site ______	Proc. Unit/Oper. ______	Checked By ______
Date ______	Proj. No. ______	Sheet 2 of 6 Page ___ of ___

WORKSHEET **15b**

COST INFORMATION

(continued)

EPA

CAPITAL COSTS (Cont.) **TOTALS**

☐ **Engineering and Procurement Costs (in-house & outside)**

- Planning ______
- Engineering ______
- Procurement ______
- Consultants ______ ______

☐ **Start-up Costs**

- Vendor ______
- Contractor ______
- In-house ______ ______

☐ **Training Costs** ______ ______

☐ **Permitting Costs**

- Fees ______
- In-house Staff Costs ______ ______

☐ **Initial Charge of Catalysts and Chemicals**

- Item #1 ______
- Item #2 ______ ______

☐ **Working Capital [Raw Materials, Product, Inventory, Materials and Supplies (not elsewhere specified)].**

- Item #1 ______
- Item #2 ______
- Item #3 ______
- Item #4 ______ ______

☐ **Estimated Salvage Value (if any)** ______

Firm ______	Waste Minimization Assessment	Prepared By ______
Site ______	Proc. Unit/Oper. ______	Checked By ______
Date ______	Proj. No. ______	Sheet 3 of 6 Page __ of __

WORKSHEET 15c

COST INFORMATION

(continued)

EPA

CAPITAL COST SUMMARY

Cost Item	Cost
Purchased Process Equipment	
Materials	
Utility Connections	
Additional Equipment	
Site Preparation	
Installation	
Engineering and Procurement	
Start-up Cost	
Training Costs	
Permitting Costs	
Initial Charge of Catalysts and Chemicals	
Fixed Capital Investment	
Working Capital	
Total Capital Investment	
Salvage Value	

Firm ______	Waste Minimization Assessment	Prepared By ______
Site ______	Proc. Unit/Oper. ______	Checked By ______
Date ______	Proj. No. ______	Sheet 4 of 6 Page __ of _

WORKSHEET 15d

COST INFORMATION

(continued)

EPA

☐ **Estimated Decrease (or Increase) in Utilities**

Utility	Unit Cost $ per unit	Decrease (or Increase) in Quantity Unit per time	Total Decrease (or Increase) $ per time
Electricity			
Steam			
Cooling Process			
Process Water			
Refrigeration			
Fuel (Gas or Oil)			
Plant Air			
Inert Air			

INCREMENTAL OPERATING COSTS • Include all relevant operating savings. Estimate these costs on an incremental basis (i.e., as decreases or increases over existing costs).

☐ **BASIS FOR COSTS** Annual ______ Quarterly ______ Monthly ______ Daily ______ Other______

☐ **Estimated Disposal Cost Saving**

Decrease in TSDF Fees ______

Decrease in State Fees and Taxes ______

Decrease in Transportation Costs ______

Decrease in Onsite Treatment and Handling ______

Decrease in Permitting, Reporting and Recordkeeping ______

Total Decrease in Disposal Costs ______

☐ **Estimated Decrease in Raw Materials Consumption**

Materials	Unit Cost $ per unit	Reduction in Quantity Units per time	Decrease in Cost $ per time

Firm ____	Waste Minimization Assessment	Prepared By ____
Site ____	Proc. Unit/Oper. ____	Checked By ____
Date ____	Proj. No. ____	Sheet 5 of 6 Page __ of __

WORKSHEET 15e

COST INFORMATION

(continued)

EPA

☐ **Estimated Decrease (or Increase) in Ancillary Catalysts and Chemicals**

Catalyst/Chemical	Unit Cost $ per unit	Decrease (or Increase) in Quantity Unit per time	Total Decrease (or Increase) $ per time

☐ **Estimated Decrease (or Increase) in Operating Costs and Maintenance Labor Costs (include cost of supervision, benefits and burden).**

____

____

____

☐ **Estimated Decrease (or Increase) in Operating and Maintenance Supplies and Costs.**

____

____

____

☐ **Estimated Decrease (or Increase) in Insurance and Liability Costs (explain).** ____________

____

____

☐ **Estimated Decrease (or Increase) in Other Operating Costs (explain).**

____

____

INCREMENTAL REVENUES

☐ **Estimated Incremental Revenues from an Increase (or Decrease) in Production or Marketable By-products (explain).**

____

____

Firm ______	Waste Minimization Assessment	Prepared By ______
Site ______	Proc. Unit/Oper. ______	Checked By ______
Date ______	Proj No. ______	Sheet 6 of 6 Page __ of __

WORKSHEET 15 f

COST INFORMATION

(continued)

EPA

INCREMENTAL OPERATING COST AND REVENUE SUMMARY (ANNUAL BASIS)

Decreases in Operating Cost or Increases in Revenue are Positive.
Increases in Operating Cost or Decrease in Revenue are Negative.

Operating Cost/Revenue Item	$ per year
Decrease in Disposal Cost	
Decrease in Raw Materials Cost	
Decrease (or Increase) in Utilities Cost	
Decrease (or Increase) in Catalysts and Chemicals	
Decrease (or Increase) in O & M Labor Costs	
Decrease (or Increase) in O & M Supplies Costs	
Decrease (or Increase) in Insurance/Liabilities Costs	
Decrease (or Increase) in Other Operating Costs	
Incremental Revenues from Increased (Decreased) Production	
Incremental Revenues from Marketable By-products	
Net Operating Cost Savings	

Firm ________	Waste Minimization Assessment	Prepared By ________
Site ________	Proc. Unit/Oper. ________	Checked By ________
Date ________	Proj. No. ________	Sheet 1 of 1 Page ___ of ___

WORKSHEET 16

PROFITABILITY WORKSHEET # 1
PAYBACK PERIOD

EPA

Total Capital Investment ($) (from Worksheet 15c) ________

Annual Net Operating Cost Savings ($ per year) (from Worksheet 15f) ________

Payback Period (in years) $= \dfrac{\text{Total Capital Investment}}{\text{Annual Net Operating Cost Savings}} =$ ________

Firm ______	**Waste Minimization Assessment**	Prepared By ______
Site ______	Proc. Unit/Oper. ______	Checked By ______
Date ______	Proj. No. ______	Sheet 1 of 1 Page __ of __

WORKSHEET **17**

PROFITABILITY WORKSHEET #2
CASH FLOW FOR NPV, IRR

EPA

Cash incomes (such as net operating cost savings and salvage value) are shown as positive. Cash outlays (such as capital investments and increased operating costs) are shown as negative.

Line		Constr. Year 0	Operating[1] Year 1	2	3	4	5	6	7	8
A	Fixed Capital Investment									
B	+ Working Capital									
C	Total Capital Investment									
D	Salvage Value[2]									
E	Net Operating Costs Savings									
F	- Interest on Loans									
G	- Depreciation									
H	Taxable Income									
I	- Income Tax[3]									
J	Aftertax Profit[3]									
K	+ Depreciation									
L	- Repayment of Loan Principal									
M	- Capital Investment (line C)									
N	+ Salvage Value (line D)									
O	Cash Flow									
P	Present Value of Cash Flow[4]									
Q	Net Present Value (NPV)[5]									
	Present Worth[6] (5% discount)	1.0000	0.9524	0.9070	0.8638	0.8227	0.7835	0.7462	0.7107	0.6768
	(10% discount)	1.0000	0.9091	0.8264	0.7513	0.6830	0.6209	0.5645	0.5132	0.4665
	(15% discount)	1.0000	0.8696	0.7561	0.6575	0.5718	0.4972	0.4323	0.3759	0.3269
	(20% discount)	1.0000	0.8333	0.6944	0.5787	0.4823	0.4019	0.3349	0.2791	0.2326
	(25% discount)	1.0000	0.8000	0.6400	0.5120	0.4096	0.3277	0.2621	0.2097	0.1678

1 Adjust table as necessary if the anticipated project life is less than or more than 8 years.
2 Salvage value includes scrap value of equipment plus sale of working capital minus demolition costs.
3. The worksheet is used for calculating an aftertax cash flow. For pretax cash flow, use an income tax rate of 0%.
4 The present value of the cash flow is equal to the cash flow multiplied by the present worth factor.
5 The net present value is the sum of the present value of the cash flow for that year and all of the preceeding years.
6 The formula for the present worth factor is $\frac{1}{(1+r)^n}$ where n is years and r is the discount rate.
7 The internal rate of return (IRR) is the discount rate (r) that results in a net present value of zero over the life of the project.

Firm ______	Waste Minimization Assessment	Prepared By ______
Site ______	Proc. Unit/Oper. ______	Checked By ______
Date ______	Proj. No. ______	Sheet 1 of 1 Page __ of __

WORKSHEET 18

PROJECT SUMMARY

EPA

Goals/Objectives ______

Task	Deliverable	Task Leader	Manhours	Budget	Duration			Reference
					Wks	Start	Finish	
1.								
2.								
3.								
4								
5								
6								
7.								
8.								
9.								
10.								
11.								
12.								
13.								
14.								
15.								
16.								
17.								
18.								
19.								
20.								
21.								
22.								
23.								
		TOTALS						

Approval By ______ Date ______

Authorization By ______ Date ______

Project Started (Date) ______

Firm ____	Waste Minimization Assessment	Prepared By ____
Site ____	Proc. Unit/Oper. ____	Checked By ____
Date ____	Proj. No. ____	Sheet 1 of 1 Page __ of __

WORKSHEET 19

OPTION PERFORMANCE

EPA

WM Option Description ____________________

☐ Baseline (without option) ☐ Projected ☐ Actual

(a) Period Duration ________ From ________ To ________

(b) Production per Period ________ Units (________)

(c) Input Materials Consumption per Period

Material	Pounds	Pounds/Unit Product

(d) Waste Generation per Period

Waste Stream	Pounds	Pounds/Unit Product

(e) Substance(s) of Concern - Generation Rate per Period

Waste Stream	Substance	Pounds	Pounds/Unit Product

Appendix B
Simplified Waste Minimization Assessment Worksheets

The worksheets that follow are designed to facilitate a simplified WM assessment procedure. Table B-1 lists the worksheets, according to the particular phase of the program, and a brief description of the purpose of the worksheets. The worksheets here are presented as supporting only a preliminary effort at minimizing waste, or in a situation where a more formal rigorous assessment is not warranted.

Table B-1. List of Simplified WM Assessment Worksheets

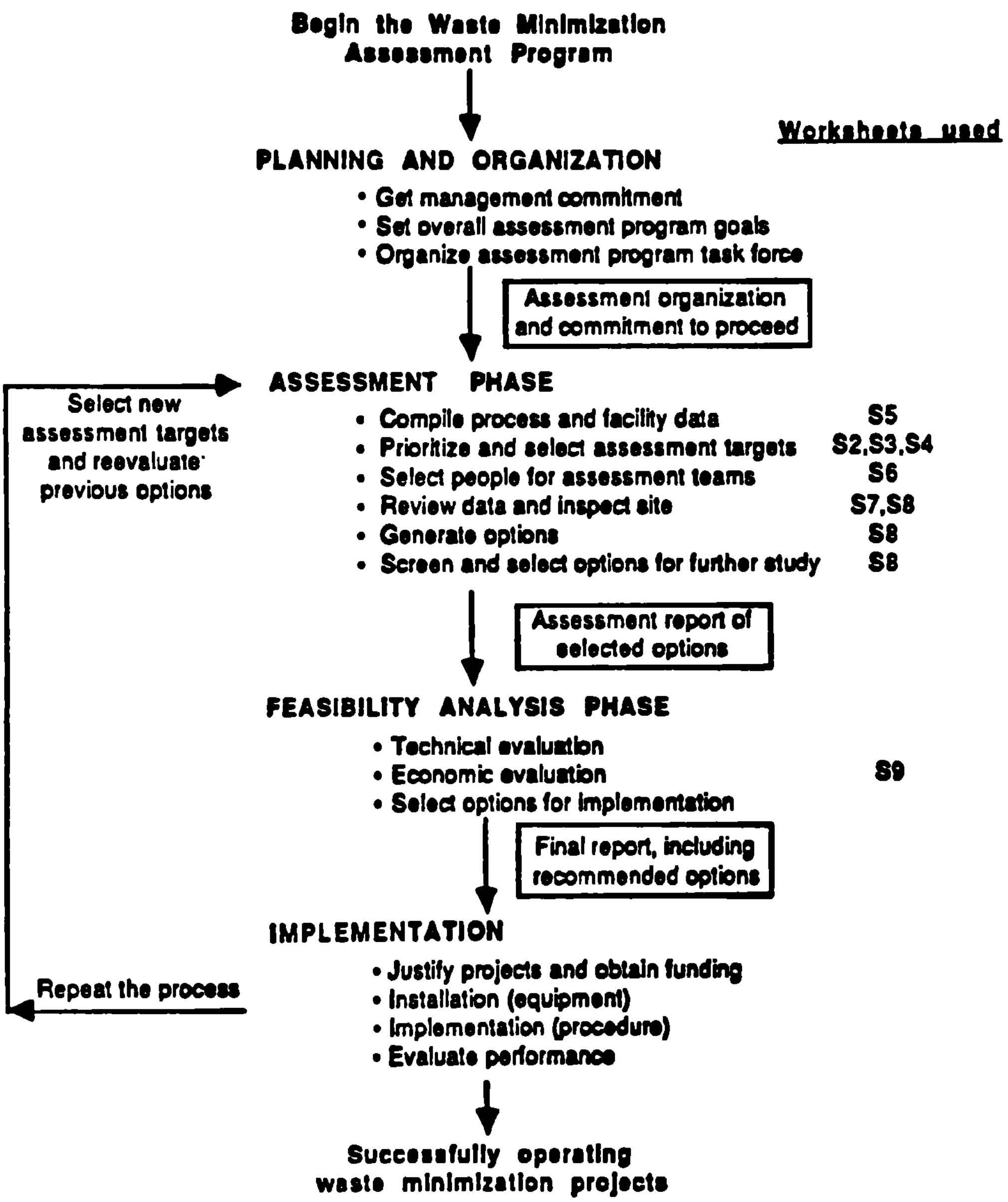
Phase	Number and Title	Purpose/Remarks
	S1. Assessment Overview	Summarizes the overall assessment procedure.
Assessment Phase (Section 3)		
	S2. Site Description	Lists background information about the facility, including location, products, and operations.
	S3. Process Information	This is a checklist of useful process information to look for before starting the assessment.
	S4. Input Materials Summary	Records input material information for a specific production or process area. This includes name, supplier, hazardous component or properties, cost, delivery and shelf-life information, and possible substitutes.
	S5. Products Summary	Identifies hazardous components, production rate, revenues, and other information about products.
	S6. Waste Stream Summary	Summarizes all of the information collected for each waste stream. This sheet is also used to prioritize waste streams to assess.
	S7. Option Generation	Records options proposed during brainstorming or nominal group technique sessions. Includes the rationale for proposing each option.
	S8. Option Description	Describes and summarizes information about a proposed option. Also notes approval of promising options.
Feasibility Analysis Phase (Section 4)		
	S9. Profitability	This worksheet is used to identify capital and operating costs and to calculate the payback period.

Firm ______	Waste Minimization Assessment Simplified Worksheets	Prepared By ______
Site ______		Checked By ______
Date ______	Proj. No. ______	Sheet 1 of 1 Page ___ of ___

WORKSHEET S1

ASSESSMENT OVERVIEW

EPA



Firm ______	Waste Minimization Assessment Simplified Worksheets	Prepared By ______
Site ______		Checked By ______
Date ______	Proj. No. ______	Sheet 1 of 1 Page __ of __

WORKSHEET **S2**

SITE DESCRIPTION

EPA

Firm:
Plant:
Department:
Area:
Street Address:
City:
State/ZIP Code:
Telephone: ( )
Major Products:
SIC Codes:
EPA Generator Number :
Major Unit or:
Product or:
Operations:
Facilities/Equipment Age:

Firm ______ Site ______ Date ______	Waste Minimization Assessment Simplified Worksheets Proj. No. ______	Prepared By ______ Checked By ______ Sheet 1 of 1 Page __ of __

WORKSHEET S3

PROCESS INFORMATION

EPA

Process Unit/Operation: ______

Operation Type: ☐ Continuous ☐ Discrete ☐ Batch or Semi-Batch ☐ Other ______

Document	Status					
	Complete? (Y/N)	Current? (Y/N)	Last Revision	Used in this Report (Y/N)	Document Number	Location
Process Flow Diagram						
Material/Energy Balance						
Design						
Operating						
Flow/Amount Measurements						
Stream						
Analyses/Assays						
Stream						
Process Description						
Operating Manuals						
Equipment List						
Equipment Specifications						
Piping & Instrument Diagrams						
Plot and Elevation Plan(s)						
Work Flow Diagrams						
Hazardous Waste Manifests						
Emission Inventories						
Annual/Biennial Reports						
Environmental Audit Reports						
Permit/Permit Applications						
Batch Sheet(s)						
Materials Application Diagrams						
Product Composition Sheets						
Material Safety Data Sheets						
Inventory Records						
Operator Logs						
Production Schedules						

Firm ____ Site ____ Date ____	Waste Minimization Assessment Simplified Worksheets Proj. No. ____	Prepared By ____ Checked By ____ Sheet 1 of 1 Page __ of __

WORKSHEET S4

INPUT MATERIALS SUMMARY

EPA

Attribute	Description		
	Stream No.____	Stream No.____	Stream No.____
Name/ID			
Source/Supplier			
Component/Attribute of Concern			
Annual Consumption Rate			
Overall			
Component(s) of Concern			
Purchase Price, $ per ______			
Overall Annual Cost			
Delivery Mode[1]			
Shipping Container Size & Type[2]			
Storage Mode[3]			
Transfer Mode[4]			
Empty Container Disposal/Management[5]			
Shelf Life			
Supplier Would			
• accept expired material (Y/N)			
• accept shipping containers (Y/N)			
• revise expiration date (Y/N)			
Acceptable Substitute(s), if any			
Alternate Supplier(s)			

1 e.g., pipeline, tank car, 100 bbl. tank truck, truck, etc.
2 e.g., 55 gal. drum, 100 lb. paper bag, tank, etc.
3 e.g., outdoor, warehouse, underground, aboveground, etc.
4 e.g., pump, forklift, pneumatic transport, conveyor, etc.
5 e.g., crush and landfill, clean and recycle, return to supplier, etc.

Firm ______	Waste Minimization Assessment Simplified Worksheets	Prepared By ______
Site ______		Checked By ______
Date ______	Proj. No. ______	Sheet 1 of 1 Page __ of __

WORKSHEET S5

PRODUCTS SUMMARY

EPA

Attribute	Description		
	Stream No.____	Stream No.____	Stream No.____
Name/ID			
Component/Attribute of Concern			
Annual Production Rate			
Overall			
Component(s) of Concern			
Annual Revenues, $ ______			
Shipping Mode			
Shipping Container Size & Type			
Onsite Storage Mode			
Containers Returnable (Y/N)			
Shelf Life			
Rework Possible (Y/N)			
Customer Would			
• relax specification (Y/N)			
• accept larger containers (Y/N)			

Firm ______	Waste Minimization Assessment Simplified Worksheets	Prepared By ______
Site ______	Proc. Unit/Oper. ______	Checked By ______
Date ______	Proj. No. ______	Sheet 1 of 1 Page __ of __

WORKSHEET S6

WASTE STREAM SUMMARY

EPA

Attribute		Description					
		Stream No.____		Stream No.____		Stream No.____	
Waste ID/Name:							
Source/Origin							
Component/or Property of Concern							
Annual Generation Rate (units________)							
Overall							
Component(s) of Concern							
Cost of Disposal							
Unit Cost ($ per: ________)							
Overall (per year)							
Method of Management[1]							
Priority Rating Criteria[2]	Relative Wt. (W)	Rating (R)	R x W	Rating (R)	R x W	Rating (R)	R x W
Regulatory Compliance							
Treatment/Disposal Cost							
Potential Liability							
Waste Quantity Generated							
Waste Hazard							
Safety Hazard							
Minimization Potential							
Potential to Remove Bottleneck							
Potential By-product Recovery							
Sum of Priority Rating Scores		Σ(R x W)		Σ(R x W)		Σ(R x W)	
Priority Rank							

Notes: 1. For example, sanitary landfill, hazardous waste landfill, onsite recycle, incineration, combustion with heat recovery, distillation, dewatering, etc.

2. Rate each stream in each category on a scale from 0 (none) to 10 (high).

Firm ____	Waste Minimization Assessment Simplified Worksheets	Prepared By ____
Site ____	Proc. Unit/Oper. ____	Checked By ____
Date ____	Proj. No. ____	Sheet 1 of 1 Page __ of __

WORKSHEET S7

OPTION GENERATION

EPA

Meeting format (e.g., brainstorming, nominal group technique) ____

Meeting Coordinator ____

Meeting Participants ____

List Suggested Options	Rationale/Remarks on Option

Firm ______	Waste Minimization Assessment Simplified Worksheets	Prepared By ______
Site ______	Proc. Unit/Oper. ______	Checked By ______
Date ______	Proj. No. ______	Sheet 1 of 1 Page __ of __

WORKSHEET S8

OPTION DESCRIPTION

EPA

Option Name: ______

Briefly describe the option ______

______

______

______

______

______

______

______

Waste Stream(s) Affected: ______

______

Input Material(s) Affected: ______

______

Product(s) Affected: ______

______

Indicate Type:

☐ Source Reduction

- __ Equipment-Related Change
- __ Personnel/Procedure-Related Change
- __ Materials-Related Change

☐ Recycling/Reuse

- __ Onsite __ Material reused for original purpose
- __ Offsite __ Material used for a lower-quality purpose
- __ Material sold
- __ Material burned for heat recovery

Originally proposed by: ______ Date: ______

Reviewed by: ______ Date: ______

Approved for study? ______ yes ______ no, by: ______

Reason for Acceptance or Rejection ______

Firm ______	Waste Minimization Assessment Simplified Worksheets	Prepared By ______
Site ______	Proc. Unit/Oper. ______	Checked By ______
Date ______	Proj No. ______	Sheet 1 of 1 Page __ of __

WORKSHEET S9

PROFITABILITY

EPA

Capital Costs

Purchased Equipment ______

Materials ______

Installation ______

Utility Connections ______

Engineering ______

Start-up and Training ______

Other Capital Costs ______

Total Capital Costs ______

Incremental Annual Operating Costs

Change in Disposal Costs ______

Change in Raw Material Costs ______

Change in Other Costs ______

Annual Net Operating Cost Savings ______

$$\text{Payback Period (in years)} = \frac{\text{Total Capital Costs}}{\text{Annual Net Operating Cost Savings}} = \_\_\_\_\_\_$$

Appendix C
Waste Minimization Assessment Example
Amalgamated Metal Refinishing Corporation

The following case study is an example of a waste minimization assessment of a metal plating operation. This example is reconstructed from an actual assessment, but uses fictitious names. The example presents the background process and facility data, and then describes the waste minimization options that are identified and recommended for this facility.

Amalgamated Metal Refinishing Corporation is in the business of refinishing decorative items. The corporation owns and operates a small facility in Beverly Hills, California. The principal metals plated at this facility are nickel, brass, silver, and gold.

Preparing for the Assessment

Since the facility is a small one with a rather small number of employees, an assessment team was assembled that included both company personnel and outside consultants. The team was made up of the following people:

- Plant manager (assessment team leader)
- First shift plating supervisor
- Corporate process engineer
- Plating chemistry consultant
- Environmental engineering consultant

The assessment team chose to look at all of the plating operations, rather than focusing on one or two specific plating processes.

The assessment began by collecting recent production records, input material information, equipment layout drawings and flow diagrams, waste records, and plant operator instructions. After each of the team members had reviewed the information, a comprehensive inspection of the plating room was carried out. The following process, layout, and waste descriptions summarize the information that was collected for the assessment.

Process Description

Items brought in for refinishing are cleaned, electroplated and polished The basic operations include paint stripping, cleaning, electroplating, drying, and polishing.

In silver plating, the original plated metal is stripped off the item by dipping it into a sodium cyanide solution with the system run in reverse current. This is followed by an acid wash in a 50% muriatic acid solution. The item is then polished to a bright finish. The polished item is then cleaned with caustic solution to remove dirt, rinsed with a 5% sulfuric acid solution to neutralize any remaining caustic solution on the item, and rinsed with water. The item is now ready for electroplating

After the item is immersed in the plating tank for the required amount of time, it is rinsed in a still rinse tank, followed by a continuous water rinse. Tap water is used for both the still and continuous rinsing steps. Solution from the still rinse tank is used as make-up for the plating baths.In places where two still rinse tanks are used, water from the second tank is used to replenish the first still rinse tank. Overflow from the continuous rinse tank is discharged as wastewater. The item is polished following the plating step.

Gold plating generally does not require stripping After the initial cleaning operation, the item is electroplated. Nickel and brass plating are also done in a similar manner. Vapor degreasing using 1,1,1-trichloroethane is often perfomed on brass- and nickel-plated items to remove oil and grease. In some cases, items are first nickel-plated and then plated with gold, silver, or brass.

For electroplating operations, the constituents of the cyanide solutions must be kept at an optimum concentration. The solutions are analyzed twice a month by an outside laboratory. A representative sample from a tank is obtained by dipping a tube to the bottom of the plating tank. The sample is analyzed and recommendations for make-up are made based on the test results. Table C-1 shows a typical analysis for brass and nickel electroplating solutions, respectively. This table also shows the optimum concentrations for each constituent in the baths, as well as the recommended make-up and/or dilution requirements.

All plating operations at the facility are performed manually. The facility operates one shift per day and employs eight operators.

Equipment Layout Description

All plating, cleaning, and rinse tanks are located in one room at the plating shop, while an adjacent room houses all equipment used for buffing and polishing.

Table C-1. Electroplating Solution Analyses

	Concentrations	
	Optimum	Actual
Brass Plating		
Copper metal	-	7.52 oz/gal
Zinc metal	0.3 oz/gal	0.80
Sodium cyanide	6.0	3.54
Sodium hydroxide	8.0	7.50
Copper cyanide	10.0	10.60
Zinc cyanide	0.5	1.45
Rochelle salts	2.0	3.59
Nickel Plating		
Nickel metal	-	16.65 oz/gal
Nickel chloride	8.0 oz/gal	15.66
Boric acid	6.0	6.92
Nickel sulfate	40.0	57.26
A-5	2.5%	2.86%
SA-1	1.2%	1.38%
pH	4.0	4.5

Table C-2. Wastewater characteristics

Sampling date	August 8, 1987
Sampling location	Clarifier Sample Box
Type of sample	Time Composite
Reporting period	July '87 to August '87
Total flow in	322 gallons
Total flow out	290 gallons
Peak flow	1.5 gallons per minute
Suspended solids	1.0 mg/L
pH	7.5
Total cyanide	1.0 mg/L
Total chromium	0.42 mg/L
Copper	1.30 mg/L
Nickel	0.93 mg/L
Silver	<0.05 mg/L
Oil and grease	0.2 mg/L
Temperature	70°F

Figure C-1 is a plan of the facility. The area north of the buffing room is used for drying and storage purposes. Finished goods, as well as raw materials, are stored in the front of the building.

Thirty tanks are used in cleaning and electroplating operations. Figure C-1 includes the names and normal working volumes of these tanks. The configuration of a typical plating unit includes a plating bath, followed by one ore two still tanks and a continuous rinse tank. Except for nickel plating, all plating and stripping solutions used at the facility are cyanide-based.

Waste Stream Description

Cyanide waste is generated from silver stripping; from silver, gold, brass, and copper electroplating; and from the associated rinsing operations. The principal waste streams are wastewater from the continuous rinse tanks and from floor washings, and plating tank filter waste.

Aqueous streams generated from paint stripping, from metal stripping and electroplating, and from floor washings are routed to a common sump. This sump discharges to the sanitary sewer. Table C-2 presents the results of a typical analysis on the wastewater.

Metal sludges accumulate in the plating tanks. This sludge is filtered out of the plating solution once a month using a portable dual cartridge filter. Two filter cartridges are used for each plating tank. Cartridges are typically replaced every two to three months.

The sump is pumped out and disposed of as hazardous waste once every six months. When pumped out the sump usually contains 300 to 400 gallons of sludge comprised of dirt, stripped paint, and a solution containing cyanide and heavy metals.

Proposed Waste Minimization Options

After the site inspection was completed and additional information was reviewed, the team held a brainstorming session to identify potential waste minimization options for the facility. The following options were proposed during the meeting:

- Reduce solution drag-out from the plating tanks by:
  - Proper positioning of workpiece on the plating rack.
  - Increasing plating solution temperatures.
  - Lowering the concentration of plating solution constituents.
  - Increase the recovery of drag-out with drain boards.
- Extend plating solution bath life by:
  - Reducing drag-in by better rinsing.
  - Using deionized make-up water.
  - Using purer anodes.
  - Returning spent solutions to the suppliers.
- Reduce the use of rinse water by:
  - Using multiple countercurrent rinse tanks.
  - Using still rinsing.
  - Using spray or fog rinsing.
- Prevent dust from the adjacent buffing and polishing room from entering the plating room and contaminating the plating baths.
- Segregate cyanide wastes from the rinse tanks from other wastewater streams, such as floor washings and paint stripping wastes.

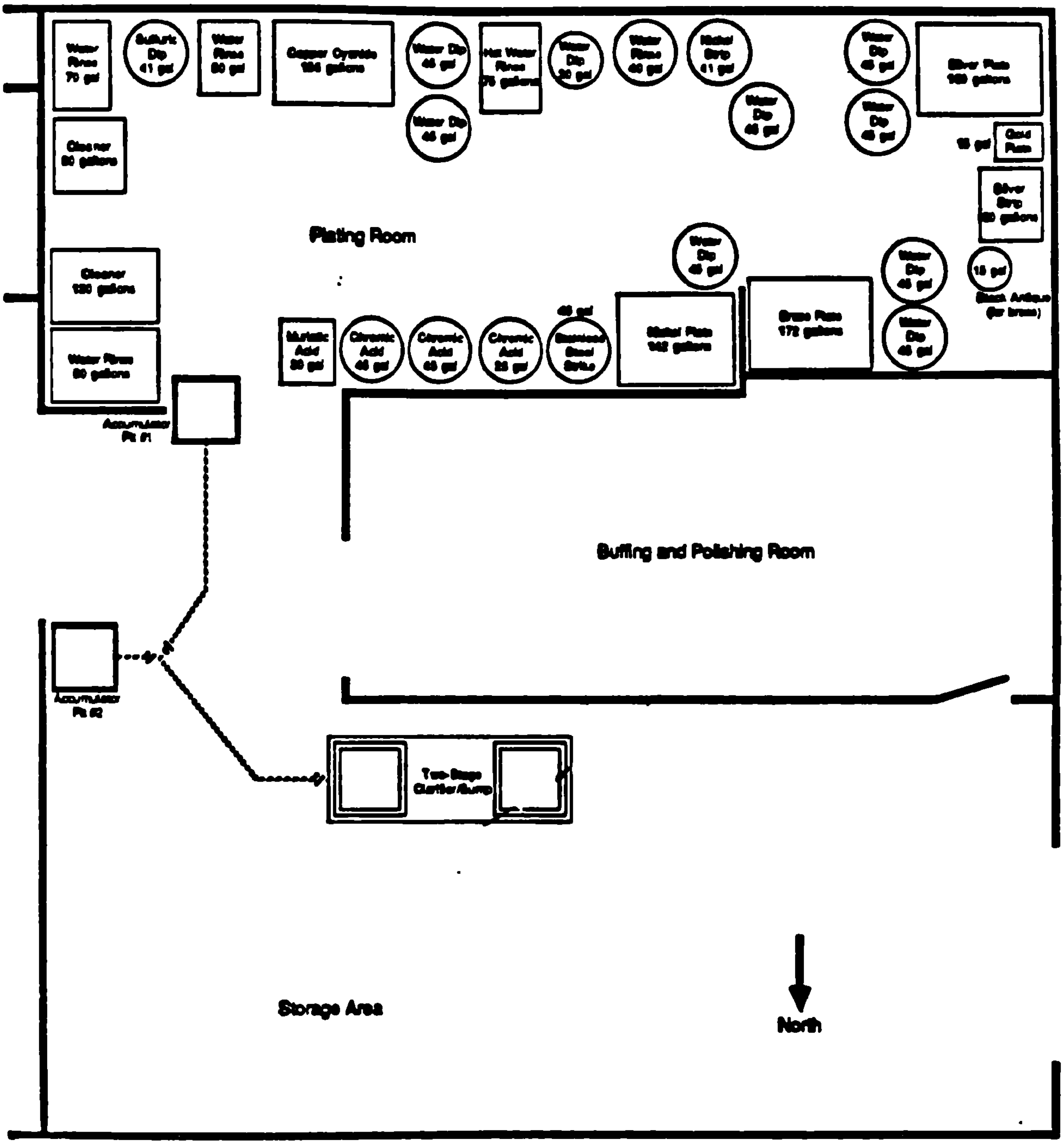


Figure C-1. PLANT LAYOUT

Amalgamated Metal Refinishing Corporation
Worldwide Headquarters and Production Facilities
Beverly Hills, California

The team members each independently reviewed the options and then met to decide which options to study further. The team chose the following options for the feasibility analysis:

- Reduce drag-out by using drain boards.
- Extend bath life using deionized water for make-up.
- Use spray rinsing to reduce rinsewater usage.
- Segregate hazardous waste from nonhazardous waste.

Feasibility Analysis

The assessment team conducted technical and economic feasibility analyses on each of the four options.

Segregate Hazardous Wastes

The assessment team recognized that segregating hazardous wastes from nonhazardous wastes could be implemented at virtually no cost and would save money immediately. There were no identified technical problems.

Use Drain Boards to Reduce Drag-out

Drain boards are used to collect plating solution that drips off the rack and the workpiece after they are pulled out of the plating tank. The plating solution drains back into the plating tank. This option reduces the amount of dilute rinse water waste, but impurities build up faster in the plating solution. Since drag-out is reduced, make-up chemical consumption is reduced.

The purchase price of drain boards is estimated at $115, with installation costs of $200, for a total capital cost of $315. This option is expected to reduce rinse water disposal costs by $500 per year, and reduce make-up chemicals costs by $400 per year. The resulting payback period is 0.35 years, or about 4 months.

Use Deionized Water for Make-up Solutions and Rinse Water

Using DI water will reduce the build-up of impurities in the plating solutions. In particular, the build-uphardness minerals from tap water will be avoided. This, in turn, will avoid the precipitation of carbonates in the plating tanks.

The assessment team decided to combine the evaluation of this option with the previous option of using drain boards. The initial purchase and installation of the deionizer was $267. When adding the cost of the drain boards, the total capital cost of this option is $582. The deionizer is rented and serviced by an outside water treating service company for $450 per year. The savings in disposal costs and make-up chemical costs is $900 per year. Therefore, the annual net operating cost savings is $450 per year. The payback period is 1.3 years.

Install Spray Rinses

Installing spray rinses will reduce the amount of rinse water required to clean the items. With spray rinse nozzles and controls, rinsing can be done on demand. Rinse water usage was estimated to be reduced by 50%. The resulting rinse wastewater is more concentrated and some can be returned to the plating tanks as a water make-up.

The assessment team determined that four spray rinse units would cost $2,120, plus an additional $705 for piping, valves, and installation labor. The total capital cost was $2825. The reduction in disposal costs were estimated at $350 per year, based on a 50% reduction in rinse wastewater. This resulted in a payback of over 8 years.

Implementation

The procedures for segregating hazardous wastes from nonhazardous wastes was implemented before the feasibility analysis was completed for the other three options. The installation of drain boards and the purchase of a water deionizer were made shortly after the feasibility analysis was completed. The DI water system was online two months later. The assessment team decided not to implement the spray rinse option because of the long payback period.

Future WM Assessments

During the next cycle of waste minimization assessments, the assessment team will review previously suggested options in the plating area and will look at ways to reduce the generation of metallic dust in the buffing and polishing area. In the meantime, the assessment team will continue to look for additional opportunities to reduce waste throughout the facility.

Appendix D
Typical Causes and Sources of Waste

In order to develop a comprehensive list of waste minimization options for a facility, it is necessary to understand the sources, causes, and controlling factors that influence waste generation. The tables in this Appendix list this information for common industrial operations.

Table D-1. Typical Wastes from Plant Operations

Table D-2. Causes and Controlling Factors of Waste Generation

Table D-1. Typical Wastes from Plant Operations

Plant Function	Location/Operation	Potential Waste Material
Material Receiving	Loading docks, incoming pipelines, receiving areas	Packaging materials, off-spec materials, damaged containers, inadvertant spills, transfer hose emptying
Raw Material and Product Storage	Tanks, warehouses, drum storage yards, bins, storerooms	Tank bottoms; off-spec and excess materials; spill residues; leaking pumps, valves, tanks, and pipes; damaged containers, empty containers
Production	Melting, curing, baking, distilling, washing, coating, formulating, reaction	Washwater; rinse water; solvents; still bottoms; off-spec products; catalysts;empty containers; sweepings; ductwork clean-out; additives; oil; filters; spill residue; excess materials; process solution dumps; leaking pipes, valves, hoses, tanks, and process equipment
Support Services	Laboratories	Reagents, off-spec chemicals, samples, empty sample and chemical containers
	Maintenance shops	Solvents, cleaning agents, degreasing sludges, sand-blasting waste, caustic, scrap metal, oils, greases
	Garages	Oils, filters, solvents, acids, caustics, cleaning bath sludges, batteries
	Powerhouses/boilers	Fly ash, slag, tube clean-out material, chemical additives, oil empty containers, boiler blowdown, water-treating chemical wastes
	Cooling towers	Chemical additives, empty containers, cooling tower bottom sediment, cooling tower blowdown, fan lube oils

Source: adapted from Gary Hunt and Roger Schecter, "Minimization of Hazardous Waste Generation", Standard Handbook of Hazardous Waste Management, Harry Freeman, editor, McGraw-Hill, New York (currently in press).

Table D-2. Causes and Controlling Factors in Waste Generation

Waste/Origin	Typical Causes	Operational Factors	Design Factors
Chemical Reaction	• Incomplete conversion • By-product formation • Catalyst deactivation (by poisoning or sintering)	• Inadequate temperature control • Inadequate mixing • Poor feed flow control • Poor feed purity control	• Proper reactor design • Proper catalyst selection • Choice of process • Choice of reaction conditions
Contact between aqueous and organic phases	• Condensate from steam jet ejectors • Presence of water as a reaction by-product • Use of water for product rinse • Equipment cleaning • Spill clean-up	• Indiscriminate use of water for cleaning or washing	• Vacuum pumps instead of steam jet ejectors • Choice of process • Use of reboilers instead of steam stripping
Process equipment cleaning	• Presence of cling • Deposit formation • Use of filter aids • Use of chemical cleaners	• Drainage prior to cleaning • Production scheduling to reduce cleaning frequency	• Design reactors or tanks wiper blades • Reduce cling • Equipment dedication
Heat exchanger cleaning	• Presence of cling (process side) or scale (cooling water side) • Deposit formation • Use of chemical cleaners	• Inadequate cooling water treatment • Excessive cooling water temperature	• Design for lower film temperature and high turbulence • Controls to prevent cooling water from overheating
Metal parts cleaning	• Disposal of spent solvents, spent cleaning solution, or cleaning sludge	• Indiscriminate use of solvent or water	• Choice between cold dip tank or vapor degreasing • Choice between solvent or aqueous cleaning solution
Metal surface treating	• Dragout • Disposal of spent treating solution	• Poor rack maintenance • Excessive rinsing with water • Fast removal of workpiece	• Countercurrent rinsing • Fog rinsing • Dragout collection tanks or trays
Disposal of unusable raw materials or off-spec products	• Obsolete raw materials • Off-spec products caused by contamination, improper reactant controls, inadequate pre-cleaning of equipment or workpiece, temperature or pressure excursions	• Poor operator training or supervision • Inadequate quality control • Inadequate production planning and inventory control of feedstocks	• Use of automation • Maximize dedication of equipment to a single function
Clean-up of spills and leaks	• Manual material transfer and handling operations • Leaking pump seals • Leaking flange gaskets	• Inadequate maintenance • Poor operator training • Lack of attention by operator • Excessive use of water in cleaning	• Choice of gasketing materials • Choice of seals • Use of welded or seal-welded construction

Source: Jacobs Engineering Group

Appendix E
Waste Minimization Techniques

The tables in this appendix lists techniques and practices for waste reduction in operations that are applied in a wide range of industries. Most of the techniques listed here are source reduction techniques

Source: Jacobs Engineering Group

Table E-1. Waste Minimization Options for Coating Operations

Waste	Source/Origin	Waste Reduction Measures	Remarks	References
Coating overspray	Coating material that fails to reach the object being coated	• Maintain 50% overlap between spray pattern • Maintain 6" - 8" distance between spray gun and the workpiece • Maintain a gun speed of about 250 feet/minute • Hold gun perpendicular to the surface • Trigger gun at the beginning and end of each pass	The coated object does not look streaked, and wastage of coating material is avoided. If the spray gun is arched 45°, the overspray can be as high as 65%.	1,2
		• Proper training of operators		2
		• Use robots for spraying		2
		• Avoid excessive air pressure for coating atomization	By air pressure adjustment,... overspray can be reduced to 40%.	2
		• Recycle overspray		3
		• Use electrostatic spray systems	Overspray can be reduced by 40%.	4
		• Use air-assisted airless spray guns in place of air-spray guns	Increases transfer efficiency.	4
Stripping wastes	Coating removal from parts before applying a new coat	• Avoid adding excess thinner	Reduces stripping wastes due to rework.	5
		• Use abrasive media stripping	Solvent usage is eliminated.	
		• Use bead-blasting for paint stripping	Solvent usage is eliminated.	6
		• Use cryogenic stripping	Solvent usage is eliminated.	7
		• Use caustic stripping solutions	Solvent usage is eliminated.	8
		• Clean coating equipment after each use		1
Solvent emissions	Evaporative losses from process equipment and coated parts	• Keep solvent soak tanks away from heat sources		9
		• Use high-solids formulations	Lower usage of solvents.	
		• Use powder coatings	Avoids solvent usage.	10,11
		• Use water-based formulations	Avoids solvent usage.	4,12
Equipment cleanup wastes	Process equipment cleaning with solvents	• Light-to-dark batch sequencing • Produce large batches of similarly coated objects instead of small batches of differently coated items		13
		• Isolate solvent-based paint spray booths from water-based paint spray booths • Reuse cleaning solution/solvent • Standardize solvent usage		20
Overall		• Reexamine the need for coating, as well as available alternatives		

Table E-2. Waste Minimization Options for Equipment Cleaning Operations

Waste	Source/Origin	Waste Reduction Measures	Remarks	References
Spent solvent- or inorganic-based cleaning solutions	Tank cleaning operations	• Maximize dedication of process equipment		
		• Use squeegees to recover cling of product prior to rinsing		
		• Avoid unnecessary cleaning		
		• Closed storage and transfer systems	Scaling and drying up can be prevented.	
		• Provide sufficient drain time for liquids	Minimizes leftover material.	
		• Lining the equipment to prevent cling	Reduces cling.	18
		• "Pigging" process lines		19
		• Use high-pressure spray nozzles	Minimizes solvent consumption.	
		• Use countercurrent rinsing		
		• Use clean-in-place systems		
		• Clean equipment immediately after use	Prevents hardening of scale that requires more severe cleaning.	
		• Reuse cleanup solvent		
		• Rework cleanup solvent into useful products		
		• Segregate wastes by solvent type		
		• Standardize solvent usage		
		• Reclaim solvent by distillation		
		• Schedule production to lower cleaning frequency		
Wastewater sludges, spent acidic solutions	Heat exchanger cleaning	• Use bypass control or pumped recycle to maintain turbulence during turndown	Onsite or offsite recycling.	
		• Use smooth heat exchange surfaces	Electroplated or Teflon® tubes.	20
		• Use on-stream cleaning techniques	"Superscrubber", for example.	21
		• Use hydroblasting over chemical cleaning where possible		

Table E-3. Waste Minimization through Good Operating Practices

Good Operating Practice	Program Ingredients	Remarks	References
Waste minimization assessments	• Form a team of qualified individuals • Establish practical short-term and long-term goals • Allocate resources and budget for the program • Establish assessment targets • Identify and select options to minimize waste Periodically monitor the program's effectiveness	These programs are conducted to reduce waste in a facility.	22
Environmental audits/reviews	• Assemble pertinent documents • Conduct environmental process reviews • Carry out a site inspection • Report on and follow up on the findings	These audits are conducted to monitor compliance with regulations.	23,24
Loss prevention programs	• Establish Spill Prevention, Control, and Countermeasures (SPCC) plans • Conduct hazard assessment in the design and operating phases	SPCC plans are required by law for oil storage facilities.	3,25,26
Waste Segregation	• Prevent mixing of hazardous wastes with non-hazardous wastes • Isolate hazardous wastes by contaminant • Isolate liquid wastes from solid wastes	These measures can result in lower waste haulage volumes and easier disposal of the hazardous wastes.	4
Preventive maintenance programs	• Use equipment data cards on equipment location, characteristics, and maintenance • Maintain a master preventive maintenance (PM) schedule • Deferred PM reports on equipment • Maintain equipment history cards • Maintain equipment breakdown reports • Keep vendor maintenance manuals handy • Maintain a manual or computerized repair history file	These programs are conducted to cut production costs and decrease equipment downtime, in addition to preventing waste releases due to equipment failure.	27,28,29

Table E-3. Waste Minimization through Good Operating Practices (continued)

Good Operating Practice	Program Ingredients	Remarks	References
Training/Awareness-building programs	• Provide training for - Safe operation of the equipment - Proper materials handling - Economic and environmental ramifications of hazardous waste generation and disposal - Detecting releases of hazardous materials - Emergency procedures - Use of safety gear	These programs are conducted to reduce occupational health and safety hazards, in addition to reducing waste generation due to operator or procedural errors.	2
Effective supervision	• Closer supervision may improve production efficiency and reduce inadvertent waste generation • Management by objectives (MBO), with goals for waste reduction	Increased opportunity for early detection of mistakes. Better coordination among the various parts of an overall operation.	
Employee participation	• "Quality circles" (free forums between employees and supervisors) can identify ways to reduce waste • Solicit employee suggestions for waste reduction ideas	Employees who intimately understand the operations can identify ways to reduce waste.	
Production scheduling/planning	• Maximize batch size • Dedicate equipment to a single product • Alter batch sequencing to minimize cleaning frequency (light-to-dark batch sequence, for example) • Schedule production to minimizing cleaning frequency	Altering production schedule can have a major impact on waste minimization.	
Cost accounting/allocation	• Cost accounting done for all waste streams leaving the facilities • Allocate waste treatment and disposal costs to the operations that generate the waste	Allocating costs to the waste-producing operations will give them an incentive to cut their wastes.	

Table E-4. Waste Minimization Options in Materials Handling, Storage, and Transfer

Waste/Source	Waste Reduction Measures	Remarks	References
Material/waste tracking and inventory control	• Avoid over-purchasing • Accept raw material only after inspection • Ensure that inventory quantity does not go to waste • Ensure that no containers stay in inventory longer than a specified period • Review material procurement specifications • Return expired material to supplier • Validate shelf-life expiration dates • Test outdated material for effectiveness • Eliminate shelf-life requirements for stable compounds • Conduct frequent inventory checks • Use computer-assisted plant inventory system • Conduct periodic materials tracking • Proper labeling of all containers • Set up manned stations for dispensing chemicals and collecting wastes	These procedures are employed to find areas where the waste minimization efforts are to be concentrated.	30,31
Loss prevention programs	• Use properly designed tanks and vessels only for their intended purposes • Install overflow alarms for all tanks and vessels • Maintain physical integrity of all tanks and vessels • Set up written procedures for all loading/unloading and transfer operations • Install secondary containment areas • Forbid operators to bypass interlocks, alarms, or significantly alter setpoints without authorization • Isolate equipment or process lines that leak or are not in service • Use seal-less pumps • Use bellows-seal valves • Document all spillage • Perform overall material balances and estimate the quantity and dollar value of all losses • Use floating-roof tanks for VOC control • Use conservation vents on fixed roof tanks • Use vapor recovery systems		

Table E-4. Waste Minimization Options in Materials Handling, Storage, and Transfer (continued)

Waste/Source	Waste Reduction Measures	Remarks	References
Spills and leaks	• Store containers in such a way as to allow for visual inspection for corrosion and leaks • Stack containers in a way to minimize the chance of tipping, puncturing, or breaking • Prevent concrete "sweating" by raising the drum off storage areas • Maintain MSDSs to correctly handle spill situations • Provide adequate lighting in the storage area • Maintain a clean, even surface in transportation areas • Keep aisles clear of obstruction • Maintain distance between incompatible chemicals • Maintain distance between different types of chemicals to prevent cross-contamination • Avoid stacking containers against process equipment • Follow manufacturers' suggestions on the storage and handling of all raw materials • Insulation and inspection of electric circuitry for corrosion and potential sparking		
Cling	• Use large containers instead of small containers whenever possible • Use containers with height-to-diameter ratio equal to one to minimize wetted area • Empty drums and containers thoroughly before cleaning or disposal		

Table E-5. Waste Minimization Options for Parts Cleaning Operations

Waste	Source/Origin	Waste Reduction Measures	Remarks	References
Spent solvent	Contaminated solvent from parts cleaning operations	• Use water-soluble cutting fluids instead of oil-based fluids	This could eliminate the need for solvent cleaning.	
		• Use peel coatings in place of protective oils		
		• Use aqueous cleaners		
		• Use aqueous paint stripping solutions		8
		• Use cryogenic stripping		7
		• Use bead blasting for paint stripping		6
		• Use multi-stage countercurrent cleaning		
		• Prevent cross-contamination		
		• Prevent drag-in from other processes		
		• Prompt removal of sludge from the tank		
		• Reduce the number of different solvents used	A single, larger waste that is more amenable to recycling.	
Air emissions	Solvent loss from degreasers and cold tanks	• Use roll-type covers, not hinged covers	24 to 50% reduction in emissions.	15
		• Increase freeboard height	39% reduction in solvent emissions.	15
		• Install freeboard chillers		15
		• Use silhouette entry covers		
		• Proper equipment layout		
		• Avoid rapid insertion and removal of items	The speed that items are put into the tank should be less than 11 feet/min.	16
		• Avoid inserting oversized objects into the tank	Cross-sectional area of the item should be less that 50% of tank area to reduce piston effect.	17
		• Allow for proper drainage before removing item		
		• Avoid water contamination of solvent in degreasers		
Rinse water	Water rinse to remove solvent carried out with the parts leaving the cleaning tank	• Reduce solvent dragout by proper design and operation of rack system	The dragout can be 0.4 gal/1000 sqft, versus 24 gal/1000 sqft for poorly drained parts.	15
		• Install air jets to blow parts dry		
		• Use fog nozzles on rinse tanks		
		• Proper design and operation of barrel system		15
		• Use countercurrent rinse tanks		15
		• Use water sprays on rinse tanks	More efficient rinsing is achieved.	15

Appendix E
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Appendix F
Government Technical/Financial Assistance Programs

The EPA's Office of Solid Waste and Emergency Response has set up a telephone call-in service to answer questions regarding RCRA and Superfund (CERCLA):

(800) 424-9346 (outside the District of Columbia)
(202) 382-3000 (in the District of Columbia)

The following states have programs that offer technical and/or financial assistance in the areas of waste minimization and treatment.

Alabama
Hazardous Material Management and Resource Recovery Program
University of Alabama
P.O. Box 6373
Tuscaloosa, AL 35487-6373
(205) 348-8401

Alaska
Alaska Health Project
Waste Reduction Assistance Program
431 West Seventh Avenue, Suite 101
Anchorage, AK 99501
(907)276-2864

Arkansas
Arkansas Industrial Development Commission
One State Capitol Mall
Little Rock, AR 72201
(501) 371-1370

California
Alternative Technology Section
Toxic Substances Control Division
California State Department of Health Services
714/744 P Street
Sacramento, CA 94234-7320
(916) 324-1807

Connecticut
Connecticut Hazardous Waste Management Service
Suite 360
900 Asylum Avenue
Hartford, CT 06105
(203) 244-2007

Connecticut Department of Economic Development
210 Washington Street
Hartford CT 06106
(203) 566-7196

Georgia
Hazardous Waste Technical Assistance Program
Georgia Institute of Technology
Georgia Technical Research Institute
Environmental Health and Safety Division
O'Keefe Building, Room 027
Atlanta, GA 30332
(404) 894-3806

Georgia (continued)
Environmental Protection Division
Georgia Department of Natural Resources
Floyd Towers East, Suite 1154
205 Butler Street
Atlanta, CA 30334
(404) 656-2833

Illinois
Hazardous Waste Research and Information Center
Illinois Department of Energy and Natural Resources
1808 Woodfield Drive
Savoy, IL 61874
(217) 333-8940

Illinois Waste Elimination Research Center
Pritzker Department of Environmental Engineering
Alumni Building, Room 102
Illinois Institute of Technology
3200 South Federal Street
Chicago, IL 60616
(312) 567-3535

Indiana
Environmental Management and Education Program
Young Graduate House, Room 120
Purdue University
West Lafayette, IN 47907
(317) 494-5036

Indiana Department of Environmental Management
Office of Technical Assistance
P.O. Box 6015
105 South Meridian Street
Indianapolis, IN 46206-6015
(317) 232-8172

Iowa
Iowa Department of Natural Resources
Air Quality and Solid Waste Protection Bureau
Wallace State Office Building
900 East Grand Avenue
Des Moines, IA 50319-0034
(515) 281-8690

Center for Industrial Research and Service
205 Engineering Annex
Iowa State University
Ames, IA 50011
(515) 294-3420

Kansas
Bureau of Waste Management
Department of Health and Environment
Forbes Field, Building 730
Topeka, KS 66620
(913) 296-1607

Kentucky
Division of Waste Management
Natural Resources and Environmental Protection Cabinet
18 Reilly Road
Frankfort, KY 40601
(502) 564-6716

Louisiana
Department of Environmental Quality
Office of Solid and Hazardous Waste
P.O. Box 44307
Baton Rouge, LA 70804
(504) 342-1354

Maryland
Maryland Hazardous Waste Facilities Siting Board
60 West Street, Suite 200A
Annapolis, MD 21401
(301) 974-3432

Maryland Environmental Service
2020 Industrial Drive
Annapolis, MD 21401
(301) 269-3291
(800) 492-9188 (in Maryland)

Massachusetts
Office of Safe Waste Management
Department of Environmental Management
100 Cambridge Street, Room 1094
Boston, MA 02202
(617) 727-3260

Source Reduction Program
Massachusetts Department of Environmental Quality Engineering
1 Winter Street
Boston, MA 02108
(617) 292-5982

Michigan
Resource Recovery Section
Department of Natural Resources
P.O. Box 30028
Lansing, MI 48909
(517) 373-0540

Minnesota
Minnesota Pollution Control Agency
Solid and Hazardous Waste Division
520 Lafayette Road
St Paul, MN 55155
(612) 296-6300

Minnesota (continued)
Minnesota Technical Assistance Program
W-140 Boynton Health Service
University of Minnesota
Minneapolis, MN 55455
(612) 625-9677
(800) 247-0015 (in Minnesota)

Minnesota Waste Management Board
123 Thorson Center
7323 Fifty-Eighth Avenue North
Crystal, MN 55428
(612) 536-0816

Missouri
State Environmental Improvement and Energy Resources Agency
P.O. Box 744
Jefferson City, MO 65102
(314) 751-4919

New Jersey
New Jersey Hazardous Waste Facilities Siting Commission
Room 614
28 West State Street
Trenton, NJ 08608
(609) 292-1459
(609) 292-1026

Hazardous Waste Advisement Program
Bureau of Regulation and Classification
New Jersey Department of Environmental Protection
401 East State Street
Trenton, NJ 08625

Risk Reduction Unit
Office of Science and Research
New Jersey Department of Environmental Protection
401 East State Street
Trenton, NJ 08625

New York
New York State Environmental Facilities Corporation
50 Wolf Road
Albany, NY 12205
(518) 457-3273

North Carolina
Pollution Prevention Pays Program
Department of Natural Resources and Community Development
P.O. Box 27687
512 North Salisbury Street
Raleigh, NC 27611
(919) 733-7015

Governor's Waste Management Board
325 North Salisbury Street
Raleigh, NC 27611
(919) 733-9020

North Carolina (continued)
Technical Assistance Unit
Solid and Hazardous Waste Management Branch
North Carolina Department of Human Resources
P.O. Box 2091
306 North Wilmington Street
Raleigh, NC 27602
(919) 733-2178

Ohio
Division of Solid and Hazardous Waste Management
Ohio Environmental Protection Agency
P.O. Box 1049
1800 WaterMark Drive
Columbus, OH 43266-1049
(614) 481-7200

Ohio Technology Transfer Organization
Suite 200
65 East State Street
Columbus, OH 43266-0330
(614) 466-4286

Oklahoma
Industrial Waste Elimination Program
Oklahoma State Department of Health
P.O. Box 53551
Oklahoma City, OK 73152
(405) 271-7353

Oregon
Oregon Hazardous Waste Reduction Program
Department of Environmental Quality
811 Southwest Sixth Avenue
Portland, OR 97204
(503) 229-5913

Pennsylvania
Pennsylvania Technical Assistance Program
501 F. Orvis Keller Building
University Park, PA 16802
(814) 865-0427

Bureau of Waste Management
Pennsylvania Department of Environmental Resources
P.O. Box 2063
Fulton Building
3rd and Locust Streets
Harrisburg, PA 17120
(717) 787-6239

Center of Hazardous Material Research
320 William Pitt Way
Pittsburgh, PA 15238
(412) 826-5320

Rhode Island
Ocean State Cleanup and Recycling Program
Rhode Island Department of Environmental Management
9 Hayes Street
Providence, RI 02908-5003
(401) 277-3434
(800) 253-2674 (in Rhode Island)

Rhode Island (continued)
Center of Environmental Studies
Brown University
P.O. Box 1943
135 Angell Street
Providence, RI 02912
(401) 863-3449

Tennessee
Center for Industrial Services
102 Alumni Hall
University of Tennessee
Knoxville, TN 37996
(615) 974-2456

Virginia
Office of Policy and Planning
Virginia Department of Waste Management
11th Floor, Monroe Building
101 North 14th Street
Richmond, VA 23219
(804) 225-2667

Washington
Hazardous Waste Section
Mail Stop PV-11
Washington Department of Ecology
Olympia, WA 98504-8711
(206) 459-6322

Wisconsin
Bureau of Solid Waste Management
Wisconsin Department of Natural Resources
P.O. Box 7921
101 South Webster Street
Madison, WI 53707
(608) 266-2699

Wyoming
Solid Waste Management Program
Wyoming Department of Environmental Quality
Herschler Building, 4th Floor, West Wing
122 West 25th Street
Cheyenne, WY 82002
(307) 777-7752

Appendix G
Option Rating
Weighted Sum Method

The Weighted Sum Method is a quantitative method for screening and ranking waste minimization options. This method provides a means of quantifying the important criteria that affect waste management in a particular facility. This method involves three steps.

1. Determine what the important criteria are in terms of the WM assessment program goals a constraints, and the overall corporate goals an constraints. Examples of criteria are the following:

   - Reduction in waste quantity
   - Reduction in waste hazard (e.g., toxicity, flammability, reactivity, corrosivity, etc.)
   - Reduction in waste treatment/disposal costs
   - Reduction in raw material costs
   - Reduction in liability and insurance costs
   - Previous successful use within the company
   - Previous successful use in industry
   - Not detrimental to product quality
   - Low capital cost
   - Low operating and maintenance costs
   - Short implementation period (and minimal disruption of plant operations)
   - Ease of implementation

   The weights (on a scale of 0 to 10, for example) are determined for each of the criteria in relation to their importance.For example, if reduction in waste treatment and disposal costs are very important, while previous successful use within the company is of minor importance, then the reduction in waste costs is given a weight of 10 and the previous use within the company is given a weight of 1 or 2. Criteria that are not important are not included (or given a weight of 0).

2. Each option is then rated on each of the criteria. Again, a scale of 0 to 10 can be used (0 for low and 10 for high).

3. Finally, the rating of each option from particular criteria is multiplied by the weight of the criteria. An option's overall rating is the sum of the products of rating times the weight of the criteria.

The options with the best overall ratings are then selected for the technical and economic feasibility analyses. Worksheet 13 in Appendix A is used to rate options using the Weighted Sum method. Table G-1 presents an example using the Weighted Sum Method for screening and ranking options.

Table G-1. Sample Calculation using the Weighted Sum Method

ABC Corporation has determined that reduction in waste treatment costs is the most important criterion, with a weight factor of 10. Other significant criteria include reduction in safety hazard (weight of 8), reduction in liability (weight of 7), and ease of implementation (weight of 5). Options X, Y, and Z are then each assigned effectiveness factors. For example, option X is expected to reduce waste by nearly 80%, and is given an rating of 8. It is given a rating of 6 for reducing safety hazards, 4 for reducing liability, and because it is somewhat difficult to implement, 2 for ease of implementation. The table below shows how the options are rated overall, with effectiveness factors estimated for options Y and Z.

	Ratings for each option			
Rating Criteria	Weight	X	Y	Z
Reduce treatment costs	10	8	6	3
Reduce safety hazards	8	6	3	8
Reduce liability	7	4	4	5
Ease of implementation	5	2	2	8
Sum of weight times ratings		166	122	169

From this screening, option Z rates the highest with a score of 169. Option X's score is 166 and option Y's score is 122. In this case, option Z and option X should both be selected for further evaluation because both of their scores are high and relatively close to each other.

Appendix H
Economic Evaluation Example

The following example presents a profitability analysis for a relatively large hypothetical waste minimization project. This project represents the installation of a package unit that improves plant production while reducing raw material consumption and disposal costs. The analysis was done on a personal computer using a standard spreadsheet program. The salient data used in this evaluation are summarized below.

Capital Costs

- The delivered price of the equipment is quoted by the vendor at $170,000. This includes taxes and insurance.
- Materials costs (piping, wiring, and concrete) are estimated at $35,000.
- Installation labor is estimated at $25,000.
- Internal engineering staff costs are estimated at $7,000. Outside consultant and contractor costs are estimated at $15,000.
- Miscellaneous environmental permitting costs are estimated at $15,000.
- Working capital (including chemical inventories, and materials and supplies) is estimated at $5,000.
- Start-up costs are estimated by the vendor at $3,000.
- A contingency of $20,000 for unforeseen costs and/or overruns is included.
- Planning, design, and installation are expected to take one year.

Financing

- The project will be financed 60% by retained earnings and 40% by a bank loan.
- The bank loan will be repaid over 5 years of equal installments of principal, plus interest at an annual percentage rate of 13%. Interest accrued during installation will be added into the total capital costs.
- All capital costs, except working capital and interest accrued during construction, will be depreciated over 7 years using the double-declining balance method, switching to the straight-line method when the charges by this method become greater.
- The marginal income tax rate is 34%.
- Escalation of all costs is assumed to be 5% per year for the life of the project.
- The firm's cost of capital is 15%.

Operating Costs and Revenues

- The WM project is estimated to decrease raw materials consumption by 300 units per year at a cost of $50 per unit. The project will not result in an increased production. However, it will produce a marketable by-product to be recovered at a rate of 200 units per year and a price of $25 per unit.
- The project will reduce the quantity of hazardous waste disposed by 200 tons per year. The following items make the total unit disposal costs:

	Costs per ton of waste
Offsite disposal fees	$500
State generator taxes	10
Transportation costs	25
Other costs	25
TOTAL DISPOSAL COSTS	$560

- Incremental operating labor costs are estimated on the basis that the project is expected to require one hour of operator's time per eight-hour shift. There are three shifts per day and the plant operates 350 days per year. The wage rate for operators is $12.50 per hour.
- Operating supplies expenses are estimated at 30% of operating labor costs.
- Maintenance labor costs are estimated at 2% of the sum of the capital costs for equipment, materials, and installation. Maintenance supplies costs are estimated at 1% of these costs.
- Incremental supervision costs are estimated at 30% of the combined costs of operating and maintenance labor.
- The following overhead costs are estimated as a percentage of the sum of operating and maintenance labor and supervision costs.

Labor burden and benefit	28%
Plant overhead	25%
Headquarter overhead	20%

- Escalation of all costs is assumed to be 5% per year for the life of the project.
- The project life is expected to be 8 years.
- The salvage value of the project is expected to be zero after eight years.

Results

The four-page printout in Figures H-1 through H-4 presents the WM project profitability spreadsheet program. Figure H-1 represents the input section of the program. Each of the numbers in the first three columns represents an input variable in the program. The righthand side of Figure H-1 is a summary of the capital requirement. This includes a calculation of the interest accrued during construction and the financing structure of the project.

Figure H-2 is a table of the revenues and operating cost items for each of the eight years of the project's operating life. These costs are escalated by 5% each year for the life of the project.

Figure H-3 presents the annual cash flows for the project. The calculation of depreciation charges and the payment of interest and repayment of loan principal is also shown here. The calculation of the internal rate of return (IRR) and the net present value (NPV) are based on the annual cash flows. Since the project is leveraged (financed partly by a bank loan), the equity portion of the investment is used as the initial cash flow. The NPV and the IRR are calculated on this basis. The IRR calculated this way is referred to as the "return on equity". The program is structured to present the NPV and IRR after each year of the project's operating life. In the example, after six years, the IRR is 19.92% and the NPV is $27,227.

Figure H-4 is a cash flow table based entirely on equity financing. Therefore, there are no interest payments or deb principal repayments. The NPV and the IRR in this case are based on the entire capital investment in the project. The IRR calculated this way is referred to as the "return on investment".

The results of the profitability analysis for this project are summarized below:

Method of Financing	*IRR*	*NPV*
60% equity/40% debt	26.47%	$84,844
100% equity	23.09%	$81,625

The IRR values are greater than the 15% cost of capital, and the NPVs are positive. Therefore, the project is attractive, and should be implemented.

Waste Minimization		started 5/22/87					
Profitability Program		last changed 8/1/87					
		INPUT				CAPITAL REQUIREMENT	
Capital Cost Factors		Operating Cost/Revenue Factors					
						Construction Year	1
Capital Cost		Increased Production		Operating Labor			
Equipment	$170,000	Increased Rate, units/year	0	Operator hours/shift	1	Capital Expenditures	
Materials	$35,000	Price, $/unit	$100	Shifts/day	3	Equipment	$170,000
Installation	$25,000			Operating days/year	350	Materials	$35,000
Plant Engineering	$7,000	Marketable By-products		Wage rate, $/man-hour	$13.50	Installation	$25,000
Contractor/Engineering	$15,000	Rate, units/year	200			Plant Engineering	$7,000
Permitting Costs	$15,000	Price, $/unit	$40	Operating Supplies	30%	Contractor/Engineering	$15,000
Contingency	$20,000			(% of Operating Labor)		Permitting Costs	$15,000
Working Capital	$5,000	Decreased Raw Materials				Contingency	$20,000
Start-up Costs	$3,000	Decreased Rate, units/year	300	Maintenance Costs		Start-up Costs	$3,000
		Price, $/unit	$50	(% of Capital Costs)		Depreciable Capital	$290,000
% Equity	60%			Labor	2.00%	Working Capital	$5,000
% Debt	40%	Decreased Waste Disposal		Materials	1.00%	Subtotal	$295,000
Interest Rate on Debt, %	13.00%	Reduced Waste, tons/year	200			Interest on Debt	$14,230
Debt Repayment, years	5	Offsite Fees, $/ton	$500	Other Labor Costs		Total Capital Requirement	$309,230
		State Taxes, $/ton	$10	(% of O&M Labor)			
Depreciation period	7	Transportation, $/ton	$25	Supervision	30.0%	Equity Investment	$185,538
Income Tax Rate, %	34.00%	Other Disposal Costs, $/ton	$25	(% of O&M Labor + Supervision)		Debt Principal	$109,462
		Total Disposal Costs, $/ton	$560	Plant Overhead	25.0%	Interest on Debt	$14,230
Escalation Rates, %	5.0%			Home Office Overhead	20.0%	Total Financing	$309,230
				Labor Burden	28.0%		
Cost of Capital (for NPV)	15.00%						

Figure H-1. Input Information and Capital Investment

REVENUE AND COST FACTORS									
Operating Year Number		1	2	3	4	5	6	7	8
Escalation Factor	1.000	1.050	1.103	1.158	1.216	1.277	1.341	1.408	1.478
INCREASED REVENUES									
Increased Production		$0	$0	$0	$0	$0	$0	$0	$0
Marketable By-products		$8,400	$8,824	$9,264	$9,728	$10,216	$10,728	$11,264	$11,824
Annual Revenue		$8,400	$8,824	$9,264	$9,728	$10,216	$10,728	$11,264	$11,824
OPERATING COST/SAVINGS									
Raw Materials		$15,750	$16,545	$17,370	$18,240	$19,155	$20,115	$21,120	$22,170
Disposal Costs		$117,600	$123,536	$129,696	$136,192	$143,024	$150,192	$157,696	$165,536
Maintenance Labor		($4,830)	($5,074)	($5,327)	($5,594)	($5,874)	($6,169)	($6,477)	($6,799)
Maintenance Supplies		($2,415)	($2,537)	($2,663)	($2,797)	($2,937)	($3,084)	($3,238)	($3,399)
Operating Labor		($14,884)	($15,635)	($16,415)	($17,237)	($18,101)	($19,009)	($19,958)	($20,951)
Operating Supplies		($4,465)	($4,691)	($4,925)	($5,171)	($5,430)	($5,703)	($5,987)	($6,285)
Supervision		($5,914)	($6,213)	($6,523)	($6,849)	($7,193)	($7,553)	($7,931)	($8,325)
Labor Burden		($7,176)	($7,538)	($7,914)	($8,310)	($8,727)	($9,165)	($9,622)	($10,101)
Plant Overhead		($6,407)	($6,731)	($7,066)	($7,420)	($7,792)	($8,183)	($8,592)	($9,019)
Home Office Overhead		($5,126)	($5,384)	($5,653)	($5,936)	($6,234)	($6,546)	($6,873)	($7,215)
Total Operating Costs		$82,133	$86,278	$90,580	$95,118	$99,891	$104,895	$110,138	$115,612

Figure H-2. Revenues and Operating Costs

RETURN ON EQUITY/RETURN ON ASSETS									
Construction Year	1								
Operating Year		1	2 .	3	4	5	6	7	8
Book Value	$290,000	$207,143	$147,959	$105,685	$64,256	$22,827	$0	$0	$0
Depreciation (by straight-line)		$41,429	$41,429	$41,429	$41,429	$41,429	$41,429	$0	$0
Depreciation (by doubleDB)		$82,857	$59,184	$42,274	$30,196	$18,359	$6,522	$0	$0
Depreciation		$82,857	$59,184	$42,274	$41,429	$41,429	$22,827	$0	$0
Debt Balance	$123,692	$123,692	$98,954	$74,216	$49,478	$24,740	$2	$0	$0
Interest Payment		$16,080	$12,864	$9,648	$6,432	$3,216	$0	$0	$0
Principal Repayment		$24,738	$24,738	$24,738	$24,738	$24,738	$2	$0	$0
CASH FLOWS									
Construction Year	1								
Operating Year		1	2	3	4	5	6	7	8
Revenues		$8,400	$8,824	$9,264	$9,728	$10,216	$10,728	$11,264	$11,824
+ Operating Savings		$82,133	$86,278	$90,580	$95,118	$99,891	$104,895	$110,138	$115,612
Net Revenues		$90,533	$95,102	$99,844	$104,846	$110,107	$115,623	$121,402	$127,436
- Depreciation		$82,857	$59,184	$42,274	$41,429	$41,429	$22,827	$0	$0
- Interest on Debt		$16,080	$12,864	$9,648	$6,432	$3,216	$0	$0	$0
Taxable Income		($8,404)	$23,054	$47,922	$56,985	$65,462	$92,796	$121,402	$127,436
- Income Tax		($2,857)	$7,838	$16,293	$19,375	$22,257	$31,551	$41,277	$43,328
Profit after Tax		($5,547)	$15,216	$31,629	$37,610	$43,205	$61,245	$80,125	$84,108
+ Depreciation		$82,857	$59,184	$42,274	$41,429	$41,429	$22,827	$0	$0
- Debt Repayment		$24,738	$24,738	$24,738	$24,738	$24,738	$2	$0	$0
After-Tax Cash Flow		$52,572	$49,662	$49,165	$54,301	$59,896	$84,070	$80,125	$84,108
Cash Flow for ROE	($185,538)	$52,572	$49,662	$49,165	$54,301	$59,896	$84,070	$80,125	$84,108
Net Present Value	($185,538)	($139,823)	($102,272)	($69,945)	($38,898)	($9,119)	$27,227	$57,349	$84,844
Return on Equity		#NUM!	-32.19%	-9.62%	4.24%	12.95%	19.92%	23.85%	26.47%
26.47%									

RETURN ON INVESTMENT									
Construction Year	1								
Operating Year		1	2	3	4	5	6	7	8
Book Value	$290,000	$207,143	$147,959	$105,685	$64,256	$22,827	$0	$0	$0
Depreciation (by straight-line)		$41,429	$41,429	$41,429	$41,429	$41,429	$41,429	$0	$0
Depreciation (by double DB)		$82,857	$59,184	$42,274	$30,196	$18,359	$6,522	$0	$0
Depreciation		$82,857	$59,184	$42,274	$41,429	$41,429	$22,827	$0	$0
CASH FLOWS									
Construction Year	1								
Operating Year		1	2	3	4	5	6	7	8
Revenues		$8,400	$8,824	$9,264	$9,728	$10,216	$10,728	$11,264	$11,824
+ Operating Savings		$82,133	$86,278	$90,580	$95,118	$99,891	$104,895	$110,138	$115,612
Net Revenues		$90,533	$95,102	$99,844	$104,846	$110,107	$115,623	$121,402	$127,436
- Depreciation		$82,857	$59,184	$42,274	$41,429	$41,429	$22,827	$0	$0
Taxable Income		$7,676	$35,918	$57,570	$63,417	$68,678	$92,796	$121,402	$127,436
- Income Tax		$2,610	$12,212	$19,574	$21,562	$23,351	$31,551	$41,277	$43,328
Profit after Tax		$5,066	$23,706	$37,996	$41,855	$45,327	$61,245	$80,125	$84,108
+ Depreciation		$82,857	$59,184	$42,274	$41,429	$41,429	$22,827	$0	$0
After-Tax Cash Flow		$87,923	$82,890	$80,270	$83,284	$86,756	$84,072	$80,125	$84,108
Cash Flow for ROI	($295,000)	$87,923	$82,890	$80,270	$83,284	$86,756	$84,072	$80,125	$84,108
Net Present Value	($295,000)	($218,545)	($155,868)	($103,090)	($55,472)	($12,339)	$24,008	$54,130	$81,625
Return on Investment		#NUM!	-30.04%	-7.76%	5.26%	13.21%	17.99%	20.97%	23.09%
23.09%									

Figure H-4. Cash Flows for Return on Investment