CHAPTER 5

INDUSTRIAL WASTE AUDITING

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1 OVERVIEW

In the pursuit of *sustainable production and consumption*—as the true value of natural resources and nonrenewable energy sources are being globally perceived—wastes can no longer be viewed as substances that are spendable. Research shows that wastes traditionally discharged into natural bodies as unwanted substances still possess some economical value. What is useless in one context can be useful in other. Importantly, pollution problems can be significantly reduced if wastes can be reused and recycled instead of being discharged to natural bodies. There is a radical shift in the perception of opportunities with industrial waste, and the current tone is to *conserve and cultivate* rather than *deploy and deplete*

In many countries, the manufacturing industry is one of the largest polluting sectors, and every year enormous effort and financial resources are spent worldwide to deal with industrial waste. Therefore, from an industry perspective, a global change in the environmental perception has a profound significance. Industrial processes, management, goals, and ethics are under pressure from a rising environmental awareness. There is ever-increasing demand to externalize the environmental cost of industrial activities. Gradually, a stage is set to internalize the environmental cost, not by marginalizing environmental concerns but, contrarily, by increased environmental stewardship of products and processes.

In response the global industry is embracing proactive methods that principally focus on energy conservation and waste minimization by the application of cleaner production techniques. These techniques are progressively conceived to meet the goals of environmental and economical sustainability of industries in a more dependable way. Use of traditional *end-of-pipe* treatment of waste alone is progressively becoming inadequate to satisfy the tightening requisites of modern environmental legislations. Industrial processes are also impacted by progressive phasing out or banning of several chemicals that have been regularly used in industries. These include ozone depleting substances (ODS), and persistent organic pollutants (POPs), for example. Several national governments have pledged in various global multilateral environmental agreements to gradually eliminate such substances.

Open or global market regimes are bringing additional complications on top of environmental needs by putting up a stiff pricing competition. Over and above, the questions of sustainability are becoming more pressing as several global institutional buyers are including environmental criteria (like ISO 14000 certification or others) in the procurement specification. This is driving industries to reevaluate their activities and associated costs, which also include waste treatment cost that covers roughly 15 to 30 percent of the total operational cost. The most assertive way is to reduce energy consumption and waste generation in the first place, which improves the overall process efficiency. Several case studies proved that such proactive approaches reduce the overall production cost and environmental liabilities. Moreover, being *greener* is also helping companies to market their products with institutional buyers and attract wider public attention.

With increasing popularity and attention to proactive methods, structured methodologies are being developed to systematically explore, analyze, and implement energy conservation and waste minimization or cleaner production programs in industries. In many industries, such techniques are now being used as one of the management tools to monitor and control process efficiency and environmental liabilities.

Traditionally, environmental impacts from industry are mainly assessed based on the type, characteristic, and volume of waste that it generates. However, recent analyses show that higher use of energy create significant environmental impacts when environmental issues related to energy production are taken into account (typical example is GHG emission). Therefore, energy use and waste generation in industries have been recognized as interlinked systems in the way that the more energy is used, the more pollution is produced, and the more waste generated, the more energy is required. As such, this chapter will refer to both waste and energy, beginning with waste minimization.

2 WASTE-MINIMIZATION PROGRAMS

All manufacturing processes will require raw materials and energy to produce a product (or an intermediary) and will generate waste in some form. Each manufacturing plant is unique in the type, characteristics, and quantity of waste generation. In other words, the manufacture of specific products creates particular waste quantity and quality. Thus, it is difficult to make generalizations regarding waste.

Since manufacturing is one of the largest single polluting sectors, several driving factors are compelling the manufacturing industries to change their outlook about waste management. Six major factors are described:

1. *Changing perception of industrial pollution:* There has been a tremendous rise in awareness about industrial pollution in general public and institutions. This has forced governments to take steps to control pollution from industries.
2. *Changing legislations:* Environmental laws and regulations for industries are tougher, and implementation is more rigorous. As a result, waste treatment technologies now require a stringent level of efficiency to meet the discharge standards.
3. *Changing waste treatment and discharge costs:* As a result of tightening legislation and discharge standards, waste treatment cost is continuously increasing.
4. *Changing availability and cost of raw material and energy:* Greater demand of raw material and energy has tightened supply, causing their price to rise. This will definitely affect the cost of the finished products.
5. *Changing traditional markets and trade barriers:* The concept of protected markets is giving way to more competitive global markets. This is forcing industry to increase efficiency and reduce raw material and energy consumption. Buyers in many developed countries are progressively incorporating environmental specification (ISO 14000 certification, eco-labeling, green productivity) in their procurement processes to screen companies.
6. *Changing international commitments:* More and more national and local governments and institutions are committing to international bilateral and multilateral agreements (like UN-mediated multilateral environmental agreements) to curb pollution by reducing and eliminating known harmful substances like ozone depleting substances and persistent organic pollutants. Many of these substances are heavily used in manufacturing. This pressures industries to change their manufacturing processes and design new products.

As a result of these driving factors, many industries are taking new perspectives and strategies in handling their waste management issues, and are trying to resolve them in a more sustainable way. The current trend of waste management is to balance proactive methods with traditional reactive methods. The concept of *reactive method* is about treating the waste once it is generated, also called *end-of-pipe treatment*, while the *proactive method* includes energy and waste minimization, waste recycling and reuse, and cleaner production that reduces end-of-pipe waste. In brief, the main advantages of energy conservation and waste minimization are as follows:

- Raw material consumption can be reduced, which in turn reduces the product cost.
- Energy consumption can be reduced, thereby reducing specific energy required for the product.
- Process efficiency can be improved, increasing product yield and quality.
- Waste generation can be reduced, thereby reducing waste treatment and disposal cost.
- Waste materials can be segregated, leading to containment of hazardous and toxic waste, which in turn can improve workers' health and safety.
- Byproducts can be recovered from waste. In addition to recycle and reuse of waste, waste heat recovery and waste exchange (with other industries) can generate additional income.
- Increased environmental stewardship can lead to higher attention from institutional buyers and marketing of products.
- Investor confidence can be increased.

There are also some known barriers to implementing waste minimization:

- Some waste minimization or cleaner production techniques may involve significant capital investment.
- There may be obvious risk involved in implementing new systems.
- There is a lack of proper manpower and expertise in appropriate technology.
- There is a lack of information and awareness, especially among small and medium scale industries.
- Often there is a hesitation to change traditional ways of doing things.

The response of an industry will largely depend on several factors:

- Nature of the industrial process
- Size and structure of the firm
- Technology and information available to the company
- Economics of prevention
- Attitude of the government to control industrial pollution through legislations, incentives, and penalties

3 WASTE-MINIMIZATION CYCLE

Typically, a development cycle of industrial waste minimization programs comprises six phases: inception, audit, analysis, design and development, implementation, and evaluation, as illustrated in Figure 1. The overall goal of waste reduction and cleaner production program is to critically investigate, evaluate, design and implement such environmentally benign processes and process improvements that would minimize consumption of resources and energy and reduce waste generation in order to reduce adverse environmental impacts and effect in overall economic benefits.

These six phases can be discussed in more detail:

1. *Inception phase:* This phase comprises setting up the goals, commitments, methodologies, task force, time frame, and budget for the project. Such goals should be quantifiable, measurable, achievable, and usable to measure the success or failure of any waste minimization or cleaner production program in real terms. Senior management plays a key role in setting up the project framework, resources, and the project team.
2. *Audit phase:* In the audit phase, the relevant factory processes include management processes and waste treatment processes. These processes are thoroughly investigated to obtain a complete balance sheet of the raw material and energy input and outputs, including waste. Over and above collecting and compiling all facts and figures, the audit exercise should recommend energy and waste minimization options to attain the desired goals of the program that could be carried to the detail analysis phase.

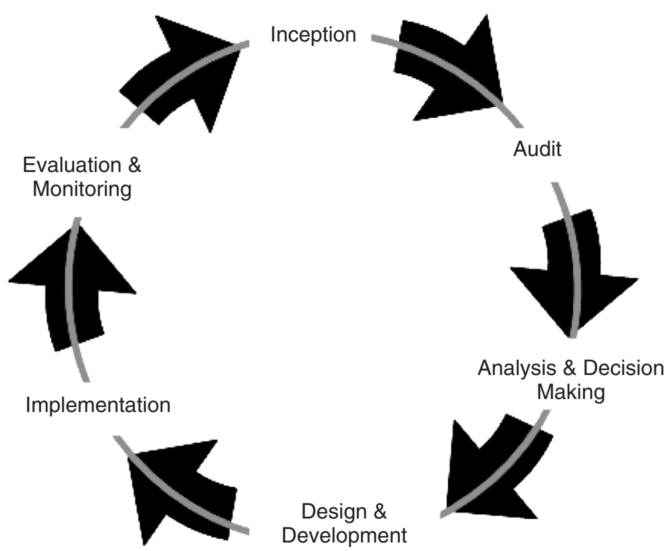

Figure 1 Typical waste minimization and cleaner production cycle.

If possible, preliminary technical and economical analysis may also be carried out to prioritize the options.

3. *Analysis phase:* The analysis phase starts with detailed analysis of the findings and recommendation from the audit phase to explore the various opportunities and risks associated with the various options. It also explores further possibilities. This phase ends with making decisions on which options to be pursued and which to be dropped.
4. *Design and development phase:* The design and development phase starts with setting up the framework of design, development, and implementation of selected options. This would require planning of all actions. It is a good idea to implement different waste minimization and cleaner production improvements in stages to reduce impacts from introducing new process and process modifications. At this stage, process changes and new processes are designed and procured, and all preparatory works for implementation are undertaken.
5. *Implementation phase:* In the implementation phase, processes and process modifications are installed and integrated to the existing system, commissioned, and put into operation. All operators and workers are trained for the changes in the process and new processes.
6. *Evaluation phase:* This phase continues after the changes or new systems are fully integrated into the normal production processes. In this phase, the actual results from the process modifications are monitored, evaluated, and compared to that originally conceived. The cost of such monitoring is normally included in routine quality assurance/quality control activities.

This chapter deals with the audit phase. It discusses different aspects of waste and energy audit systems. The scope of such discussions has been limited to waste and energy audits within a typical manufacturing industry. For the purpose of this chapter, industry would be treated in general, with specific examples from different manufacturing sectors. The methodologies described here would generally apply to most manufacturing sectors. Some modification to the described methodologies would be necessary, depending on specific activities undertaken in the industry. Such modifications are left for the industry professionals to work out according to the requirements.

4 WASTE AUDITING

Once a waste-minimization program is set to be undertaken, the physical work starts with a series of detailed surveys of ongoing activities inside the industry, starting from raw material entering the premises to finished products and byproducts (including wastes). These audits can be termed as *waste audits* or *waste-minimization audits*. The principal intent of such audits is to critically assess various inputs, processes and outputs to find methods and practices for minimizing waste and reduce the resource consumption in a more sustainable environmentally benign way. Traditionally, industrial waste audits do not include examination of the design of the product itself but investigate all activities of the production processes and opportunities of waste recycling/reuse, including waste treatment systems. Other terminologies may be used, such as pollution prevention audit, eco audit, or green audit which essentially focus on some of the common objectives of preventive approaches.

The phases of a typical waste audit process are illustrated in Figure 2. Note that an energy audit process can also be divided into similar phases. The rest of the chapter discusses each of these steps in detail with illustrations, examples, and workouts.

4.1 Phase I: Preparatory Work for a Waste Audit

Preparatory work for a waste audit consists of three main steps:

1. Getting the management and staff involved in the program
2. Forming an audit team and appointing a team leader
3. Planning the audit exercise

Once a waste minimization program is begun, it's time to provide the program with personnel, technical, and financial resources. The first step is to involve stakeholders in the program to get management and staff involved directly or indirectly in the program. This should be mainly done by one of the core management groups who would ultimately be responsible for managing the overall pollution prevention program. Normally, the production management or the environmental management group have the responsibility to execute such programs. Although all stakeholders can be involved in this process, more emphasis should be given on internal stakeholders like the management, supervisors, and workers in taking up the initiative.

Getting Management and Staff Involved

Commitment from different management groups is a decisive factor in the success of a pollution prevention program. Management representatives from all relevant departments should be involved in the program. In a typical manufacturing industry, such departments may include the following:

- Executive management (typically CEO or a deputy)
- Product development and design (if present)
- Production
- Procurement and inventory control
- Operation and maintenance
- Environmental
- Marketing

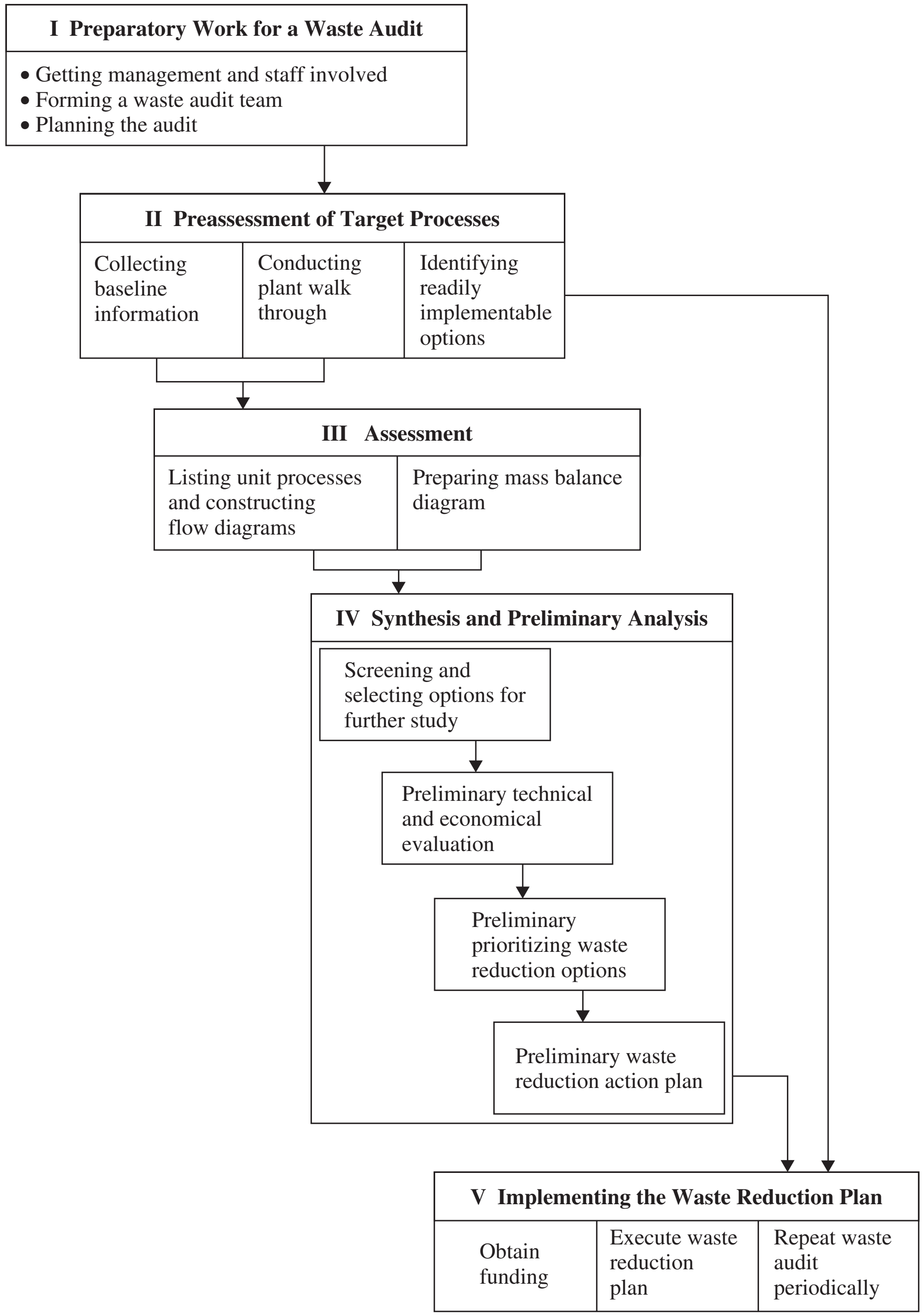

Figure 2 Steps of waste audit methodology.

- Finance
- Quality control

As the management staff would be supposedly aware of the environmental concerns and directly related to the welfare of the company, less effort would probably be required to motivate them for voluntary participation. However, it has to be confirmed that during the whole tenure of the program there is a high level of cooperation and support, even if such a program may cause short-term disruption to normal activities.

Involvement of the supervisors and workers is another key factor in the success of such programs. They have the hands-on involvement with each of the individual activities of the factory. In order to make the best use of their day-to-day experience with the machineries, processes, and a myriad of issues with the factory processes, audit exercise should be carried out with their full involvement and support. Typically, the barrier to such an involvement is fear on the part of certain supervisors and workers that a waste audit will expose inefficiencies that lead to job cuts. In order to overcome such a barrier, supervisors and workers should be assured of their job security, barring evidence of Fraud or sabotage.

The exercise can also be used as an opportunity to create more employee awareness about the environmental issues and energy and waste-minimization and cleaner-production program. Rewards in the form of bonuses, prizes, or acknowledgment would motivate employees to voluntarily participate in the program. There are several common ways of raising interest and motivation that could benefit the program (Box 1).

Box 1 Common Ways to Raise Interest in Waste and Energy Minimization Program

- Use posters or banners to inform the staff about the pollution scenario and the requirements, benefits, objectives, and goals of the upcoming waste minimization and cleaner production program.
- Publicize the upcoming audit exercise.
- Provide some prominent identification mark (like badges) to the members of the audit team and also provide them some special privileges like free access to any place or information, etc. during the audit program.
- Organize ‘‘Environment Week,’’ with programs such as speeches, videos, skits, or tree planting.
- Offer cash prizes/monetary incentives for the staff members who come up with innovative idea leading to cleaner production.

- Offer incentives for the machine operators/staff for quality production with minimum resources.
- Hold inter-departmental competition for waste minimization.
- Share the financial gains due to waste/energy minimization programs.

Formation of an Audit Team

One of the key requirements of an audit exercise is to form a proper and balanced audit team that would be responsible for all subsequent audit works. The team is normally formed by the direction of the responsible management group, in discussion with senior management and all other management groups. If required, expert advice from external consultant may be sought at this stage.

Waste audit is an interdisciplinary activity. Therefore, the team should be formed with diversified expertise from representative groups or departments, which will have major contribution and interest in the program. Usually, an audit team is a subset of the project team but may include various other personnel whose contribution may be useful. For example, an audit team can be formed from these groups:

- Environmental managers
- Plant managers
- Process or operation and maintenance engineers
- Occupational health and safety officers
- Supervisors and operators
- Laboratory technicians

The team should appoint a team leader, who will lead the audit team and coordinate the activities of all other team members. The plant manager or the environmental manager can be prospective candidates for team leader. It is recommended that a balanced audit team should be made up of three to six persons, including the team leader. This recommendation is based on typical industry structures but may be varied. In practice, the selection of the team leader and composition of the audit team will depend on the nature of the processes in the industry, scope of audit, and the scale of the industry.

Each of the audit team members should be aware of the goals and objectives of the overall energy and waste minimization program and should be able to contribute to it. The team leader should delegate duties to each of the members, depending on strength and capabilities, and should monitor them throughout auditing phase. Members of the audit team should be relieved from their routine activities during the audit exercise.

The requirement of external consultants or experts in the team would depend on the objectives of the program and complexity of the industrial processes. If the goals are to explore simple and readily applicable waste minimization or cleaner production opportunities (e.g., reduction in general water and electricity consumption), plant engineers and supervisors may be sufficient for auditing purposes. However, if the requirement is complex, such as performance of cryogenic units or distillation columns, experts in these technologies may be required. In these cases, hiring ~~of~~ an external consultant may be justified.

Planning the Audit Exercise

Before the actual audit exercise is undertaken, a substantial amount of planning work is to be done in order to carry out the audit within time and budget and least interference to normal activities of the plant. Such planning works would mainly include the following:

- Define the scope of the waste audit.
- Develop an audit program.
- Prepare specific workplan and checklists.
- Develop uniform reporting procedures.
- Inform all departments about upcoming audit programs.

However, depending on the specific need of the program, additional works may be added to the list.

Defining Scope of the Waste Audit. Determining the scope of an audit is one of the fundamental steps before taking up the actual auditing process. Scope should be defined according to the goals and objectives of the waste minimization program. Goals should be quantitative, realistic, and achievable. Compliance with a set of legislative requisites within a fixed time period could be the prime goal in some instances. In other instances, there could be the need to reduce (by a certain percentage) the operation of waste treatment cost by reducing the quantity and strength of some priority pollutants (e.g., chromium, copper, or organic pollutants like phenols, cyanides, etc.). In some other cases, the goal may be to reduce consumption of chemicals (by certain tonnes per unit product) by improving certain processes. Waste audits can also focus on specific objectives such as improving the general environmental management system in environmental management system audits, improving operational health and safety by reducing use of toxic chemicals in operational health and safety audits, or total environmental risk audits, and so forth. In every case, there should be some target sectors or processes, which have to be closely scrutinized. Identification of these target processes is crucial in defining the scope. The most common target processes of waste or energy audits are as follows:

- *Production processes:* All unit production processes in the plant need to be audited to check for process inputs, outputs, operating conditions and controls, and process efficiency.

- *Inventory processes:* Inventory processes like storage and handling of chemicals, machine parts, and other accessories need to be evaluated to check loss of material while handling or storage, loss of chemicals that have expired, and so on.
- *Housekeeping processes:* Housekeeping practices should be audited in order to check various losses during cleaning, arranging, and various types of maintenance practices. Better housekeeping practices can reduce leaks, spills, dragout, losses in rinsing, cleaning, and so on.
- *Waste treatment processes:* All waste treatment processes such as effluent treatment plants, gas treatment, and dust filters should be audited to determine treatment efficiency, operating conditions and controls, and so on.
- *Packaging processes:* Packaging sometimes requires specialized systems that can generate wastes. Therefore, such processes must also be audited if waste generation or energy consumption is high in such processes.

Unless the scope of the waste audit is positioned to achieve the overall goals of the program, many efforts can go waste. Table 1 shows how some of the common objectives are related to the target processes. Defining anything more than what is required or less may result in a poor outcome. For example, if the objective of a waste-minimization project is to reduce water consumption in a factory, only those processes/activities (target processes) that are using significant amount of water need to be checked. In this case, it is not particularly useful to audit inventory processes or final packaging systems that consume no water or very little water. However, when the goals are to explore opportunities of electricity reduction, probably all activities need to be audited, as there are practically no areas in a factory where electricity is not consumed. But in the first instance, it may be

Table 1 Audit of Target Processes as per Objectives of Waste-minimization Program

Main Objective	Target Processes
Legislative compliance	Probably all processes, with more emphasis on production and waste treatment processes.
Reduction of toxic and hazardous wastes	Production and inventory processes where hazardous and toxic chemicals are used. Special attention to be given on transport, handling, storage, and use of such chemicals, as well as treatment and disposal of the hazardous wastes.
Operational health and safety Improvement	Special attention to production processes, especially with high temperature, high voltage applications, etc. Attention to be given to handling, storage, and use of hazardous and toxic chemicals. Housekeeping processes need to be checked as well.
Compliance audit	Mainly the effluent treatment units only, with emphasis to check if they are meeting the required discharge standards.

better to audit those sections where large amounts of electricity are consumed. The scope can thus be much wider compared to water-reduction programs.

Defining a balanced scope is not generally a one-step procedure. Starting with preliminary scope, the audit team may modify the scope as the audit is undertaken and new information emerges, which may need extension of scope to certain target processes and elimination of certain other sectors that may not significantly contribute to the overall objective. The scope should also be subjected to debate by all team members of the program to arrive at a consensus.

Develop an Audit Program. Like all other projects, an audit exercise should stick to a program and plan to avoid any overrun. The audit team should develop a series of programs for auditing each of the target processes and timeframe for each of the activities. Generally, for a complete waste and energy reduction audit, the following time frames can be used for manufacturing plants:

- Small scale (less than 50 workers): 3 to 4 weeks
- Medium scale (50–100 workers): 4 to 6 weeks
- Large scale (more than 100 workers): 6 to 10 weeks

This timeframe is generalized; several factors like the number of steps in the production process, the degree of complexity, the level of automation, the quantity, and characteristics of different feedstock used should be considered for determining the timeframe. In the absence of any specific condition for the program, there are two ways of setting up an audit program:

1. Follow the material flow path though the industry.

2. Audit target processes according to the significance in terms of waste reduction.

Both systems have some merits. For example, following the material flow helps keep good track of several raw material as these are transformed into products and byproducts, which gives a complete account of material inputs and outputs. While auditing according to priority of target processes, allow a thorough investigation of major target processes that can identify more waste-minimization opportunities. Development of program is a dynamic activity and can be modified as more and more audit exercises are undertaken and new clues evolve.

Audit timing and frequency are important factors in planning audit exercises. Timing and frequency can be fixed, depending on the following:

- Type (continuous, batch, etc.) of the production process
- Number of parameters to be audited
- Scale of production
- Accuracy of audited information required

Auditing can be scheduled during peak production hours or uniformly throughout a complete production cycle, depending on the nature of the production process.

For example in a typical batch production process (like textile dyeing), quantity of wastewater discharged at the end of each cycle need to be audited, while in a continuous production process (like pulp processing in a pulp and paper industry), discharge of wastewater may be monitored at four-hour intervals. Care should be taken not to disrupt the normal factory processes.

It is recommended that the major target processes are audited more than once, typically three times, to obtain good representative results and to assure repeatability of the information, while less important sectors can be audited once. Quality and reliability of an audit exercise would very much depend on the frequency of audit on each process, as each time a process is studied, there is an increased chance of getting a new clue.

Prepare Specific Workplan and Checklists. Each team member should prepare his or her own specific workplan and checklists, depending on the nature of the activities to be audited. Preparing workplan and checklists would enable auditors to focus on key activities to be audited and collect all necessary information for those processes and activities. Some understanding of the processes would be required to prepare the workplan and checklists.

Develop Uniform Reporting Procedures. The audit report is the final product from the audit phase. All subsequent activities would very much depend on the audit report, and its importance in the program is substantial. It is therefore recommended that the audit report should be well planned and easily comprehensible, and should contain all the information that may be required during the subsequent phases. The contents of the report should be determined based on the objectives of the program. A typical table of contents ~~of~~ for a waste audit report is given in Box 2. Depending on the requirement, some of the sections can be excluded. However, important sections should be retained in a good audit report.

Box 2 Table of Contents for a Typical Waste Audit Report

- Title Page
- Disclaimer, if any (disclaiming responsibility by the publisher for data or views expressed)
- Table of Contents
- Executive Summary (summarizing the complete audit exercise in the industry)
- Problem Statement, Objectives, and Priorities
- Adopted Approach and Reasoning

- Process Layout, Description, and Observations
- Sources and Quantities of Pollution Load Generated
- Existing Treatment Facilities and Additional Requirements
- Observations on Proposed Treatment Systems
- Integrated Pollution Prevention Strategy
- Generation of Options, Screening
- Option Grouping and Prioritization
- Identification of Candidate Systems
- System Evaluation Criteria
- Calculations
- Method and Results of System Evaluation
- Recommendations
- Implementation Strategy
- Suggestions to the Management
- Summary and Observations
- Appendices (Tables, Graphs, Assumptions, and Calculations)

Inform All Departments about Upcoming Audit Programs. Once the audit program is finalized, the audit team should notify all the respective departments about the upcoming audit. This would enable the departments to be prepared for the audit. The program should be advertised at suitable locations throughout the factory to remind the supervisors and workers about the audit schedule.

4.2 Phase II: Preassessment of Target Processes

The purpose of the preassessment is to collect all information on the target processes that may be required in detailed analysis:

- Collect baseline information.
- Conduct a Plant Walkthrough.
- Identify immediate implementable options.

Collection of Baseline Information

Collection and compiling of information is one of the major tasks and purposes of waste auditing. While information on target processes would be of primary value, practical experience shows that various other information may be useful. As such, the scope of data collection can range over the entire cross-section of the factory:

- *Organizational data:* Organizational chart, factory layout, and site plan are included. Also collect information about the surrounding area indicating topography, water bodies, hydrology, agricultural areas, and human settlements.
- *Material and product data:* Data include specifications of feedstock, process water, product and byproducts with composition, instruction on usage and discharge, material safety data sheets, and usable and storage life. Information on quality assurance and quality control of feedstock, process water, products, and byproducts must also be collected.
- *Raw material and logistic consumption data:* Feedstock, energy, and water consumption records are important. Possible source of records of feedstock consumption can be available from stores and accounts department. Water usage can be obtained from water meters or bills, and energy usage from energy bills.
- *Process data:* Collect process flow diagrams, block diagrams, material balance diagrams, control and operational logic diagrams and instructions, manufacturer's data on each machine and process, and maintenance plans and records.
- *Environmental data:* Collect data on air emission, solid waste generation and effluent from different machineries, including waste treatment systems, environmental directives, and licenses.
- *Management data:* It is important to document the number of staff, their position and responsibilities, performance records, administrative instruction, occupational and safety procedures, quality assurance, and quality control procedures.
- *Financial data:* Product, utility and raw material cost, cost of waste treatment, operating and maintenance cost are available as part of the company's financial statements.
- *Industry data:* If possible, gather all of the data for industries of similar nature. Such information, though difficult to obtain, would however allow comparison with other plants that may help in defining realistic targets and goals.

All the audit members should be well familiar with the information that would allow them to objectively carry out the audit. To an experienced auditor, even scanning through such information can also give some clue about the opportunities, which areas need to be audited in detail, and room to improve the audit exercise. All information should be properly preserved and sources of such information should be noted to check the reliability at a later date.

All information should be checked for underlying data quality in terms of correctness and repeatability. If possible, historical data should be gathered over a period of time (suggested two to three years' records) and the process of data collection should be continued during the entire audit phase on a monthly or quarterly basis. It is suggested that statistical analysis be performed on the collected data to ensure quality of data before these are used for analysis purpose.

Plant Walkthrough Survey

A thorough walkthrough the plant is an essential part of the preassessment phase. It is recommended that all team members be involved in such audit exercise, which should generally be carried out over few days, with one or two sections covered in each day. Moreover, the audit team should be accompanied by the responsible section manager, engineer, or supervisor who is completely aware of each activity in the respective section. All types of management and technical information should be available during such surveys for the audit team to check. There are several benefits of such exercise:

- It is quite likely (especially in the case of large industries) that the members of the audit team may not be very familiar with the different activities carried out in each section other than their own. Therefore, this exercise would give them a chance to get conversant with many more activities and processes.
- It can reveal some obvious waste-minimization or cleaner-production options that may not need a detailed assessment to work out the recommendation. A common sense approach, or simple calculations with a lesser degree of accuracy or thumb rule estimates, may be sufficient for arriving at the conclusion. For instance, in situations where the steam pipes are not insulated or valves are leaking, there is no need to carry out a detailed assessment of energy or steam losses to arrive at the recommendation to insulate the steam pipes or repair the valves.
- By eliminating such obvious options, the auditors can narrow down the scope to those areas that require detailed assessment. This frees up some resources, and the auditors can then concentrate on more intriguing issues.
- With a balanced team of auditors, personnel from other sections or departments can more critically observe activities of another department. This can give rise to lateral thinking, and more avenues for improvement can be explored.

The best strategy for the walkthrough is to follow the material flow path through of the industry—from the storage of raw material, through various production processes, until it is converted to the final product and stored, in absence of any other plan. During the walkthrough exercise, each member of the audit team should take detailed note of all the activities, facts, and figures, and any other information that may be useful at a later stage. It is suggested that even trivial observations are noted, as these can form some clue at a later stage. It is preferred that the auditors should prepare their own sketches, schematic arrangements, material flow diagram, block diagrams, and site plans during this walkthrough exercise. Even if some process diagrams are already present, often minor changes are carried out in the plant during operations. Notes of such changes should be taken. At the end, team members should prepare their own report of the plant walkthrough.

Identification of Readily Implementable Options

After carrying out the plant walkthrough and making detailed notes, the audit team must discuss the various observations made and should identify a number of simple and obvious measures to reduce waste generation. Such options should be simple, quickly implementable, and inexpensive. Significant waste reductions can often be achieved by such options, which are based on improved operation, better handling, and tightening up of housekeeping practices. For example, simple measures such as attending to leaking hoses or installing automatic level controllers may lead to significant water savings.

Segregation of waste is arguably one of the numerous measures that can effectively lead to waste reduction. It is the most central of such options, and is a universal issue that needs to be addressed. Segregation of waste can offer enhanced opportunities for recycling and reuse with resultant savings in raw material costs, at the same time reducing treatment costs. Concentrated simple wastes are more likely to be of value than dilute or complex wastes. The waste collection and storage facilities should be reviewed to determine if waste segregation is possible.

Such options are implemented as soon as possible without waiting for the final recommendations. Typically, implementation of such options should be completed within two to three weeks. If implemented, the performance and impacts of the changes should be closely monitored and included in the audit report. All the modifications made should be noted, and these will have to be considered in the later stage while developing the detailed process flow diagram.

It is expected that at the end of the preassessment phase, the audit team is

- Organized and aware of detailed scope
- Aware of all target process layouts for further audit
- Aware of all unit operations in each of the target processes
- Aware of sources of waste and their causes

At the end of the preassessment, the plant personnel should be well informed of audit purposes. Resources should be secured, and readily implemented waste-reduction measures should be identified and, if possible, implemented.

4.3 Phase III: Assessment

This phase can be broadly divided into two steps:

1. List the unit processes and constructing flow diagrams.
2. Prepare a mass balance diagram.

Listing of Unit Operations and Constructing Process Flow Diagrams

This step is essential for an audit program, as it gives a detailed insight into the production operations/process vis-à-vis sources of waste generation and hence enables identification of avenues for better operating practices and waste reduction.

To develop a good representative block process diagram, the audit team should undertake a detailed walkthrough in the production units and utility areas, in order to gain understanding of all the processing operations and their interrelationships. The production or plant staff should be interviewed to know about the actual operating controls, parameters, and issues. Only after conducting a detailed walkthrough and interviews with the production staff, should the audit team compile the required baseline data.

By connecting the individual unit operations in the form of a block diagram and highlighting the flow of materials, a process flow diagram can then be prepared. All the information related for example to raw materials, products/byproducts, energy, water inputs, waste discharged, material and energy flows, motion, and time should be compiled during this preassessment stage and should be presented on the block diagram.

The input and output information for each unit operation should be summarized in standard units by reference to the process flow diagram. Standardized color coding may be used to represent, say, raw material input by a black line, products by blue line, wastes by red lines and recycled stream by green lines. Intermittent operations such as cleaning, make-up, or tank dumping may be distinguished by using broken lines to link the boxes. Similar notation may be used to distinguish batch and continuous discharges.

Material Balance: Process Inputs and Outputs

In the material balance exercise, a detailed account of the process inputs and outputs is made to identify the problem areas and thus the need for improvement. Material balance is important for any waste-minimization project to identify and quantify previously unknown losses or emissions. Material balance is also useful for estimating the costs of additional installations and/or modifications.

By definition, the material balance includes materials entering and leaving a process. Inputs to a process or a unit operation may include raw materials, chemicals, water, air, and energy. Outputs include primary product, byproducts, rejects, wastewater, gaseous wastes, liquid, and solid wastes that need to be stored sent off-site for disposal and reusable or recyclable wastes (Figure 3). In its simplest form, a material balance is drawn up according to the mass conservation principle:

$$Mass\ in = Mass\ out + Generation - Consumption - Accumulation$$

If no chemical reactions occur and the process progresses in a steady state, the material balance gets simplified to

$$Mass\ in = Mass\ out$$

$$Water\ in = Water\ out + losses\ (evaporation,\ spills,\ etc.)$$

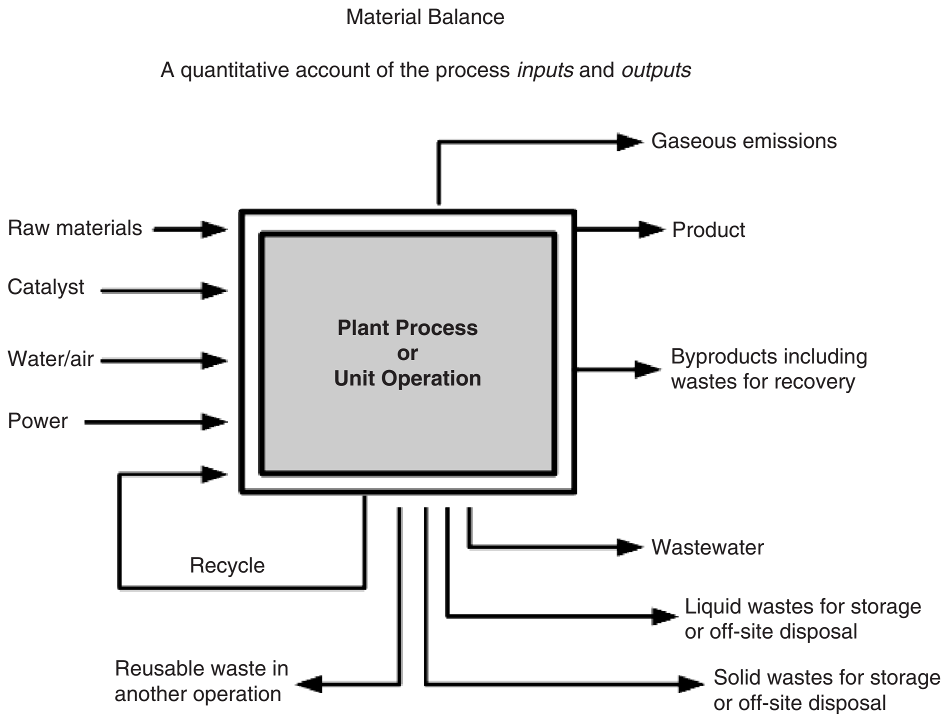

Figure 3 Schematic representation of a material balance sheet.

Sources of Information for Material Balance. There are many sources of information in establishing material balances for the various unit operations within the plant. Data may be obtained from sample analysis and measurements of raw input materials, raw material purchase records, material and emission inventories, equipment cleaning and validation procedures, batch composition records, product specifications, operating logs, standard operating procedures, and manuals.

Material balances are easier, more meaningful, and more accurate when they are done for individual production units, operations, or production processes. For this reason, it is important to define the material balance envelope or boundary limit accurately, in addition to the tie compound. Ideally, a more accurate balance should be established for the unit operation that is more critical from the waste-generation and reduction point of view, and a less accurate balance could be established for other processes.

Although it is not possible to lay precise and complete guidelines for establishing the material balance, the following guidelines might be useful:

- In the case of an extensive and complex production system, it is better to first draw up the material balance for the whole system (or even the entire production facility as such), and then concentrate on individual operations.

- When splitting up or desegregating the total system, choose the most simple, individual subsystems that are critical from the waste reduction point of view.
- Choose the material balance envelope in such a way that the number of streams entering and leaving the process is the smallest possible.
- Always choose recycle streams within the envelope to start with.

For complex waste-minimization audit, it might be desirable first to make a preliminary or draft material balance and in the second step to evaluate and refine it. However, in case of simple audit for small plants, the steps can be merged into one.

Selection of Priority Unit Operation. Although the material balance should be set up for all the unit operations, the unit operation most important from the point of view of waste generation must be identified and efforts are concentrated for that particular unit operation. This can be done by professional judgment and technical know-how of the audit team and specifically the production personnel.

Selection of Tie Compounds. A *tie compound* is the parameter (or substance) for which the material balance is established around a unit operation or a process. It is important to select an appropriate tie compound. Criteria for selecting the tie compound could be:

- Expensive raw material/intermediate
- Material common in most processing stages
- Substance of hazardous nature
- Substance/compound easy to measure/estimate

A simple example of a tie compound could be water to account for most wet operations. Establishing water balance for the processes using substantial amount of water can often provide useful clues for cleaner production. In practical situations, more specific tie compounds (e.g., nickel or zinc in electroplating shops or dyestuff in textile processing) would be ideal. Another good example could be that of chromium in leather tanning.

Chemical oxygen demand (COD) is another useful tie parameter that sharpens the material balance exercise, especially to link the production areas with the effluent treatment plant. The audit team can estimate the contribution of each process department in terms of total COD load in kg/day, knowing the volume of wastewater and the COD discharged by each department and cross checking it with the COD load observed at the treatment facilities.

One need not be very particular over the accuracy (of the order of 99%) of the material balance. In practice, such high accuracies are rarely achievable. Material balance within the tolerance range of 10 percent should generally be acceptable. However, if the tie compound for material balance is hazardous, a higher order of accuracy should be targeted.

Steps for Preparing a Material Balance. There is a logical series of steps for preparing a constructive material balance:

1. *Determine inputs.* The inputs to the process and to each unit operation need to be quantified. As a first step toward quantifying raw material usage, purchasing records should be examined; this readily gives an idea of the quantities involved. The raw materials purchases and storage and handling should be recorded in a table format in order to derive the net input to the process.

   Water is frequently used in the production process, for cooling, gas scrubbing, washouts, rinsing, and steam cleaning. The water usage needs to be accurately quantified as an input. Also, some unit operations may receive recycled material from other unit operations. These also represent an input. Hence, water and recycled materials need special attention, and therefore steps 1A and 1B describe how to evaluate these two factors.

   1A. *Record water usage.* The use of water, other than for a process reaction, should be covered in all cleaner production programs. The use of water for washing, rinsing, and cooling in process and in utility operations is often overlooked, although it represents an area where effective waste reduction can frequently be achieved simply and cheaply.

   1B. *Measure current levels of material recycling.* Some materials may be transferred from one unit to another (e.g., reuse of the final rinse in a soft-drink bottle washing plant as the initial rinse); either directly or after some modifications/treatment. If recycled materials are not properly documented, double counting may occur in the material balance, particularly at the process or complete plant level; that is, a material will be quantified as an output from one process and as an input to another. Proper attention must be paid to this issue, and care must be taken to avoid any discrepancies.

2. *Quantifying outputs.* To calculate the second half of the material balance, the outputs from unit operations and the process as a whole need to be quantified. Outputs include primary product, byproducts, wastewater, gaseous wastes (emissions to atmosphere), and liquid and solid wastes that need to be stored and/or sent off-site for disposal and reusable or recyclable wastes. It is important to identify appropriate units of measurement.

   If the product is sent off-site for sale, then the amount produced is likely to be documented in company records. However, if the product is an intermediate to be input to another process or unit operation, then the output may not be so easy to quantify. Production rates will have to be measured over a period of time. Similarly, the quantification of any byproducts may require field measurement.

2A. *Account for wastewater.* On many sites, significant quantities of both clean and contaminated water are discharged to sewers or to a watercourse. In many cases, this wastewater has environmental implications and incurs treatment costs. In addition, wastewater may wash out valuable unused raw materials from the process areas. Therefore, it is extremely important to know how much wastewater is going down the drain and what the wastewater contains. The wastewater flow, from each unit operation as well as from the entire process, must be quantified, sampled, and analyzed.

2B. *Measure gaseous emissions.* To arrive at an accurate material balance some quantification of gaseous emissions associated with the process is necessary. For example, a tea drier exhaust may carry fine particles of tea dust. Measurement in such cases calls for instruments such as thimble probe dry gas meter–vacuum pump assembly. In many instances, gaseous emissions carry some amount of hazardous materials also like volatile organic compounds (VOCs)• Expert assistance may be need determine the material/product loss through gaseous emissions.

3. *Prepare a preliminary material balance.* A material balance is designed to provide better understanding of the inputs and outputs, especially waste, of a unit operation such that areas where information is inaccurate or lacking can be identified. The initial balance should be considered as a rough assessment that must be further refined and improved.

The units of measurement should be standardized (liter, ton or kilogram) on a per day, per year, or per batch basis. The measured values in standard units should be summarized by reference to the process flow diagram. It may be necessary to modify the process flow diagram following the in-depth study of the plant. It is highly desirable to carry out a water balance for all water inputs and outputs to and from unit operations, because water imbalances may indicate underlying problems such as leaks or spills. Similarly, a detailed material balance should be carried out for important tie compound, as agreed upon by the audit team during the planning phase.

4. *Evaluate and refine material balance.* The individual and sum totals making up the material balance should be reviewed to determine information inaccuracies. Ideally, the input should equal the outputs, but in practice, this will rarely be the case. Some judgment will be required to determine what level of accuracy is acceptable. If there is a significant material imbalance, then further investigation is needed.

When constructing material balances, watch for factors that could overstate or understate waste streams. Sometimes, all or at least a few steps of material balance may need to be repeated a few times in order to refine the material balance. These may include quantification of a few input or output streams or even hunting for some material flows that might have been totally missed in the initial stage. Additional field sampling and analysis may also be required to be carried out in certain cases, and thus the data collected should again be organized and represented so as to establish an accurate material balance.

4.4 Phase IV: Synthesis and Preliminary Analysis

Phases I to II have covered planning and undertaking waste audit, resulting in the preparation of a material balance for each unit operation. Phase IV represents the interpretation of the material balance to identify process areas or components of concern. Figure 4 represent a material balance algorithm for the textile industry in establishing waste reduction options.

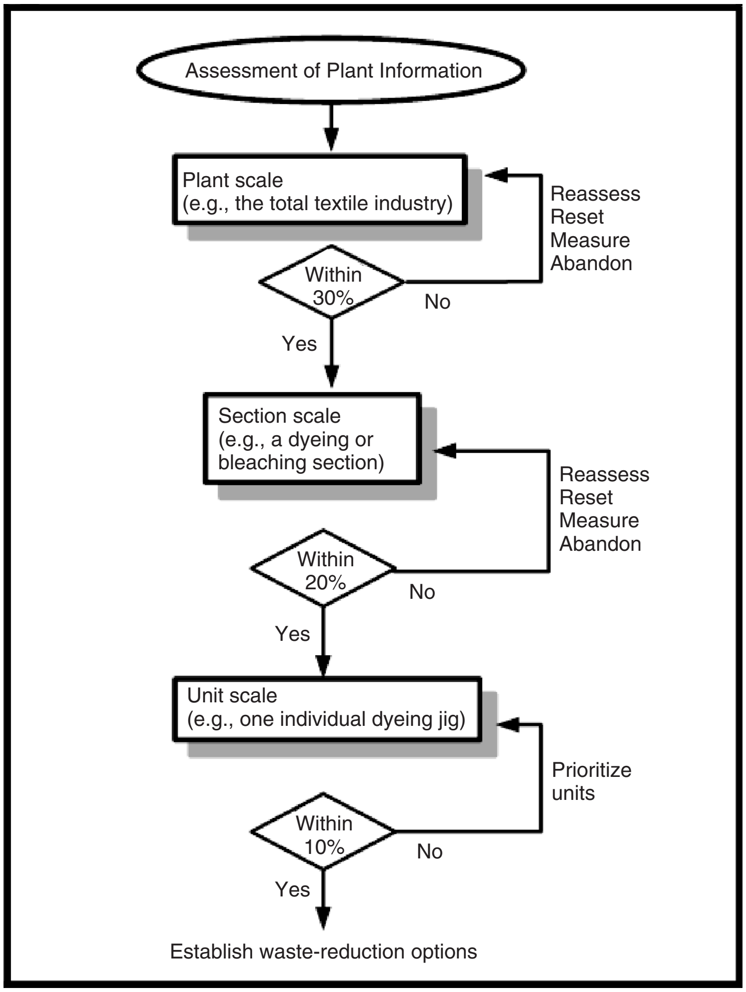

Figure 4 Material balance algorithm for textile industry.

To interpret a material balance, it is necessary to have an understanding of normal operating performance. Thus, a member of the audit team must have a good working knowledge of the process. To a trained eye, the material balance will indicate areas for concern and help to prioritize problem wastes. By using the material balance, major sources of waste may be identified, deviations from the norm in terms of waste production may be found, areas of unexplained losses may be determined, and operations that contribute to flows that exceed national or site discharge regulations may be pinpointed.

In this phase, several possible waste-reduction measures are identified that can be proceeded to the analysis phase. Different waste-minimization programs may require varying degrees of effort, time, and financial resources:

- Obvious waste-reduction measures, including improvements in management techniques and housekeeping procedures that can be implemented cheaply and quickly
- Long-term measures involving process modifications or process substitutions to eliminate problem wastes

Screening and Selecting Options for Further Study (Weighted Sum Method)
For options that require numerical evaluation, the most commonly used tool is the *weighted sum method.* Screening and selection is recommended when a large number of options have to be considered. Only those options that have sufficient merits should be carried forward. The weighted sum method provides a means of quantifying the important criteria that affect waste management in a particular industry:

1. *Determine what criteria would be considered in evaluation of the options*. The higher the degree of improvements achieve in the given criteria, the better is the result. For example, in a typical waste minimization program, such criteria can be:
    - Amount in reduction in waste quantity
    - Amount of reduction in raw material consumption
    - Amount of reduction in hazardous or toxic waste
    - Improvement in health and safety condition
    - Ease of implementation
    - Cost of implementation
    - Resource and time required

    These criteria should be determined in terms of meeting the overall waste-minimization objectives and goals. This should also take into consideration various types of constraints that may be present. Judgment would be required to select the criteria.

2. *Once the criteria are determined, each criterion should be given a weight*. The more important a criteria is, the higher is its weight. Again, a fair amount of judgment is required to determine the weight for each criterion. Generally a relative scale of 0 to 10 is used to allot weight. For example, if reduction in waste treatment and disposal costs is more important, while time of implementation is relatively less important, then the reduction in waste treatment costs is given weightage of 8 while the time of implementation is given a weight of 2 or 3.

3. *Each option is then rated for all the criteria*. A scale of 0 to 10 could be used for rating. Marks are given according to the degree the criteria are satisfied (i.e., higher marks are given when the option fulfils or satisfies the criteria and low marks when the option doesn't suit the criteria).
4. *Each rating (for the option) is multiplied by the corresponding weight of the criterion*. An option's overall rating is the sum of all the products of ratings times the weight of the criteria.

The options that carry higher marks would be carried for further analysis. Table 2 ~~presented~~ presents an option evaluation by weighted sum method.

Preliminary Technical and Economical Evaluation

Once the options are screened and selected for further analysis, preliminary technical and economical evaluation may be required to set the priority of options and develop a preliminary action plan.

Table 2 Workout Example of Weighted-sum Method for Waste Audit

		Option Rating (R)									
		#1 Option		#2 Option		#3 Option		#4 Option		#5 Option	
Criteria	Weight	R	R*W	R	R*W	R	R*W	R	R*W	R	R*W
Reduction in treatment/disposal costs	8	7	56	7	56	5	40	2	16	2	16
Reduction of input material costs	4	8	32	6	24	8	32	4	16	4	16
Extent of current use in industry	5	8	40	8	40	7	35	7	35	7	35
Extent on product quality (no effect = 10)	10	9	90	9	90	2	20	8	80	8	80
Low capital cost	5	2	10	5	25	4	20	7	35	8	40
Low operation and maintenance cost	5	5	25	6	30	5	25	8	40	8	40
Short implementation period	8	3	24	5	40	3	24	7	56	8	64
Ease of implementation	7	3	21	6	42	5	35	7	49	8	56
Reduction in energy bills	9	5	45	9	81	5	45	10	90	10	90
Improvement in OHS	7	10	70	3	21	10	70	2	14	2	14
Final Evaluation Sum of weighted ratings Σ(W*R)			413		449		346		431		451
Option ranking			4		2		5		3		1
Feasibility Analysis Scheduled for (Date)											

Technical Evaluation. The technical evaluation determines whether a proposed waste-minimization option will be technically feasible and achievable within the framework of existing constraints. A technical evaluation often begins with examining the impacts of the proposed option on production processes, production schedule, product quality, extra resource requirement, real estate requirement, operational feasibility, and safety. Several constraints such as disruption to normal production schedule, shutdowns, match of specifications (between the existing equipment and the new one), lack of technical knowledge, and trained manpower may be presented. Moreover, psychological resistance to changes may also be an issue. It is therefore recommended that all serious changes are first tested at a laboratory-scale and pilot scale. And, trial runs with the prototypes and test products are undertaken before the change is implemented and integrated to the actual production process. It is also suggested that engineers, supervisors, and operators are suitably trained for the change.

Waste-minimization options can also have some environmental impacts. During technical evaluation, the environmental effect of implementing the option needs to be checked. For example, if an option calls for recycling of rinse water, the effect of disposal of such water needs to be evaluated (as the concentration of solid in the recycled water would increase many times due to recycling), which may impact the receiving body.

Economic Evaluation. Economic feasibility is one of the most important criteria in determining the selection of an option. Unless forced by legislative requirement, there would be no cases where the economic merit of an option would be measured. Normally, each organization has its own economic criteria for selection of projects. However, three main criteria must be evaluated, irrespective of other criteria:

1. The capital, operation, and maintenance cost of the option.
2. The benefit that it would return over and above the existing system.
3. The resulting pay-back period.

The relationship between capital cost, pay-back period, and likely acceptance is given in Table 3. Pay-back period can be considered as **long** if it exceeds two years; **medium** if it is between one and two years; and **short** if less than one year for common waste minimization options.

Preliminary Prioritizing Waste Reduction Options

Once waste-minimization options are evaluated, they would need to be prioritized for further analysis, design, and implementation. A preliminary prioritization at the audit phase will expedite the process of analysis in the next phase. Prioritization can be done by weighted sum method, in absence of any special criteria (e.g., where some waste-minimization measures become mandatory due to legislative requirements, these can then be classed as high priority options, without

Table 3 Relationship between Capital Cost, Pay-back Period, and Likely Acceptance

Capital Cost	Pay-back Period	Likely Acceptance
High	Long	Low
High	Medium to Short	Medium
Medium	Long	Medium
Medium	Medium	Medium
Medium	Short	Medium to high
Low	Long	Medium to high
Low	Medium	High
Low	Short	High

further analysis). Some of the criteria that can be used to prioritize the options follow:

- Technical ease in implementation
- Resource and time requirement
- Impacts on production schedule
- Short-term capital requirement
- Pay-back period

Developing Preliminary Waste Reduction Action Plan

Upon suggesting the priority, the audit report should also delineate a preliminary action plan for implementation. This can be represented as a regular bar chart or in any other form that is acceptable. In normal cases, the implementation sequence should follow the order of priority. It is suggested that implementation of waste minimization options is taken up in stages so that the cumulative impact on production processes, resources, and finance can be kept low. It is probably best to initially implement low-cost options with relatively simple technical requirements followed by progressive implementation of more complex changes that may require higher capital costs. It may also be a good idea to implement an option and test the success of it before the next one is undertaken to reduce the total risk involved in undertaking changes.

5 CONCLUSION

Waste auditing is as important as any other step in a waste-minimization or cleaner-production project. A proper waste audit should essentially provide a platform on which the rest of the project would be built. It should be a repository of all data and information that would be required to carry out the rest of the phases. As information is the strength so is a successful waste audit.

The principal intent of a waste audit is to critically assess various inputs, processes, and outputs to find methods and practices for minimizing waste and reducing the resource consumption in a sustainable and environmentally benign way without compromising the commercial interest of the company. The waste audit phase would typically be a data collection and information synthesis phase that explores the current situation. Traditionally, an industrial waste audit also develops a list of waste minimization options and undertakes some preliminary technical and economic feasibility studies on the identified options to recommend about these options.

In general, the first step of a systematic waste audit is to prepare for the audit by forming a team, defining the scope, and programming the audit timings and budget. Scope should be defined in line with the overall objective of the waste-minimization program. The next step is to collect all baseline information, conduct plant walkthrough surveys and identify readily implementable options. This would be followed by a detailed assessment of target sectors and unit processes and performing the mass balance analysis. At the end, the data should be analyzed to build up an array of information and recommendation that would set the direction of the next phase. All data collected, information derived, and recommendation made should be presented in a form of a comprehensible and well-laid-out audit report.

It should be appreciated that a waste audit forms the vital activity of data collection and investigation of the current condition of the factory and its activities. Therefore, it is the very base of the next series of activities. The waste audit should be undertaken with utmost care and should be as thorough as possible. The more effort is spend at this phase, the better will be the chance of success of the project.

REFERENCES

• Q2 N. A. Aldokhin, A. I. Goncharov, M. A. Grachev, and A. N. Suturn, *Recycling of wastewater and* • ~~P. Bishop, *Pollution Prevention: Fundamentals and Practice*, Mc-Graw Hill, New York, 2000.~~ solid waste at the Selenginsk Pulp and Paper Plant. Industry and Environment, 13 (3-4); 21-23, 1990.

G. C. Cushnie, *Pollution Prevention and Control Technology for Plating Operations*, National Center for Manufacturing Sciences, Ann Arbor, 1994.

P. Modak, *Waste Minimization: A Practical Guide to Cleaner Production and Enhanced Profitability*, Center for Environmental Education, Ahmedabad, India, 1995.

P. M. Modak, C. Visvanathan, and M. Parasnis, “Cleaner Production Audit,” *ENSIC Review*, **32** (1995).

N. L. Nemerow, *Zero Pollution for Industry: Waste Minimization through Industrial Complexes*, John Wiley, New York, 1995.

S. Sorrell and J. Skea, *Pollution for Sale: Emission Trading and Joint Implementation*, MPG Books Ltd., Cornwall, UK, 1999.

Queries in Chapter 5

Q1. spell out VOC.

Q2. and what?