Handbook of Solid Waste Management and Waste Minimization Technologies

Nicholas P. Cheremisinoff, Ph.D.

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WASTE MINIMIZATION TECHNOLOGIES

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CONTENTS

PREFACE

This volume covers the practices and technologies that are and can be applied to the management and prevention of solid waste. It is the third volume in a series that focuses on approaches to improving environmental performance in a cost-effective manner. Earlier volumes in this Butterworth-Heinemann series are the *Handbook of Water and Wastewater Treatment Technologies* and *Handbook of Air Pollution Prevention and Control*. In addition, the book *Green Profits: The Manager's Handbook for ISO 14001 and Pollution Prevention* establishes much of the foundation for and philosophy behind these volumes.

The current volume is intended to provide engineers, environmental managers, and students with a survey of the technologies and strategies for reducing solid waste generation, and in applying resource recovery, and waste-to-energy techniques. Discussions focus on both municipal and industrial solid wastes. The interdependency of pollution and waste media cannot be readily distinguished, so in many instances relationships between waste management and pollution control and prevention strategies for air and water are included in topical discussions.

There are eight chapters to this volume. Chapter 1 provides a general overview of the principles behind source reduction and waste minimization. Although differences between the strategies behind pollution prevention (P2) and waste minimization are pointed out, they are so closely linked that both subjects are treated interchangeably at times throughout the book. Chapter 2 provides a broad overview of the U.S. environmental statutes and liabilities associated with environmental management. Although the focus is on solid waste, it would be foolish to consider only those regulations that deal with this pollution medium. All regulations dealing with the environment and public safety have a bearing on solid waste management, particularly regulated hazardous chemicals.

Chapter 3 focuses on the problem of municipal solid waste. This is a worldwide problem that impacts on the very sustainability of mankind and on the preservation of Mother Earth's natural resources. Scientific studies imply that the rate at which natural resources are being consumed exceeds the growth in renewable resources by nearly 20%. This means that our lifestyles and those of emerging nations and countries in transition which are improving their quality of life rapidly are unsustainable over the next several generations. A major philosophical change is needed in how we design and use products in our everyday lives, as well as how we view and manage wastes. We may look at solid waste as an enormous management issue that requires huge financial resources to address, or we can view the horrendous volumes of wastes as a source of renewable energy and materials recovery.

Chapter 4 discusses landfill operations and focuses on gas energy recovery. Landfilling operations are the final disposal of solid wastes. The practice should be viewed plain and simply as a practice that is uneconomical. It requires enormous effort, it has many hidden costs, it limits land redevelopment opportunities, and it poses indefinite health threats. Despite these shortcomings, it is the most widely practiced strategy for solid waste disposal worldwide. As a strategy for both industry and municipalities, it should be discouraged and phased out.

Chapter 5 provides an overview of solid waste volume reduction technologies. To reduce the costs for waste disposal, investments in these technologies are needed. These reduce waste transport and disposal fees and facilitate waste handling operations. They supplement landfilling operations, and hence, they are uneconomical from a broad sense of waste management strategies. These represent treatment technologies or in some cases they are control or end-of-pipe treatment technologies. They have high capital investments and long-term operation and maintenance costs, plus they are energy consumers. Until landfilling and incineration practices are phased out, these technologies are essential. Their one advantage is that they can be applied in P2 and waste minimization solutions, especially in developing refuse-derived fuels or in resource recovery and recycling applications.

Chapter 6 provides and overview of biosolids applications. This is a strategy that converts municipal sludges into soil conditioners and fertilizers. Although touted as a green technology by EPA, in many ways it still represents a treatment strategy. The volume of municipal sludge generated by POTWs makes this an essential post-treatment technology. More than 11% of the biosolids generated presently in the United States still winds up in landfills, and further there is significant resistance on the part of many communities using this strategy. Biosolids applications do make sense; however, it is wrong to imply that this is a green technology. There are disadvantages, and further, the economics must make sense in order for this to be applied as an effective waste management strategy.

Chapter 7 provides a summary of industry sources of waste and pollution, along with general practices and strategies for environmental management. It is intended to provide the reader with a general reference on industry strategies and an appreciation of the broad range of problems that industry deals with. Where appropriate, specific solid waste handling strategies are discussed.

Chapter 8 covers the topic of establishing pollution prevention and waste minimization programs. In order for these to be effective, they must be implemented as formalized, dedicated programs. This is best accomplished through an environmental management system or EMS. For discussions on how an EMS and P2 work hand in hand, the reader should refer to *Green Profits*. Chapter 8 expands on the principles of environmental cost accounting methods presented in Green Profits by discussing the use of life-cycle costing methods. These calculation methods are standard tools used to assess the merits of any type of investment. They are most appropriate for devising waste management strategies because they enable one to select the least costly technologies. Waste management represents a long-term investment, and as such, cost considerations are a critical consideration.

A key feature of this volume is the glossary provided at the end. The glossary contains more than 1000 terms and can serve as a handy reference for the reader in addressing waste management issues.

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ABOUT THE AUTHOR

Nicholas P. Cheremisinoff is an industry consultant specializing in pollution prevention and environmentally responsible care issues. He has more than 20 years of experience in applied research, manufacturing, and international project management, and has worked extensively throughout Russia, parts of Central and Eastern Europe, Korea, Latin America, and the United States. He has assisted and implemented projects for the World Bank Organization, the U.S. Department of Energy, the U.S. Trade and Development Agency, the U.S. Export and Import Bank, the U.S. Agency for International Development, the European Union, Chemonics International, Booz-Allen & Hamilton, and many others. Dr. Cheremisinoff has contributed extensively to the industrial press, having authored, coauthored, or edited more than 100 technical reference books, and several hundred articles. He received his B.S., M.S., and Ph.D. degrees in chemical engineering from Clarkson College of Technology. He can be reached by e-mail at ncheremisi@aol.com. Interested readers may also visit his Web site at www.ecoexpert.net.

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Chapter 1

SOURCE REDUCTION AND WASTE MINIMIZATION

INTRODUCTION

From an overall material consumption standpoint, excessive quantities of waste in society result from inefficient production processes on the industrial side, and low durability of goods and unsustainable consumption patterns on the consumer side. While total waste quantities are a reflection of the loss of resources, the hazardous components contained in product wastes and their release into the environment determine the priorities and challenges for effective waste management strategies, so that extensive environmental hazards can be avoided.

The specific challenges for waste management for municipal and industrial wastes are both similar, and yet uniquely different. Compositions of wastes within each category vary enormously, but as a general rule, industrial waste streams contain a wider variety and more concentrated forms of hazardous materials and therefore require special technologies and handling procedures.

In both categories of wastes there are major opportunities for both prevention and resource recovery. Furthermore, waste-to-energy options exist among those solid waste streams that have high organic contents, which generally is the case for many municipal wastes.

As discussed in *Green Profits: The Manager's Handbook for ISO 14001 and Pollution Prevention* (Butterworth-Heinemann Publishers, 2001), those waste management strategies that focus on source reduction and resource recovery and reuse have proven to be more cost effective over the long run, and they are less damaging to the environment simply because they prevent or minimize waste generation at the source. It is this general theme that the book focuses on. Since there is a wealth of information that exists in printed matter and on the World Wide Web concerning regulatory requirements and control and treatment technologies, discussions concerning what has become a mature industry, namely waste management in the conventional sense, are not dwelled upon. This book focuses on those strategies and technologies that prevent and minimize solid waste and various forms of pollution rather than on end-of-pipe treatment techniques and disposal practices. For example, although landfilling is the most widely adopted practice worldwide for municipal waste disposal, the reader will not find detailed discussions dealing with this subject. Aside from the fact that there is an enormous amount of published information on landfill design and operation available, landfilling along with the various treatment technologies which stabilize hazardous materials are simply not cost-effective, even though they enable companies and municipalities to meet environmental compliance. Disposal and treatment technologies require major long-term investments in capital equipment and have ongoing costs. But in addition, the waste and pollution that are treated and disposed of still persist, posing continuous and future threats to the public and environment.

This chapter lays the foundation for those approaches that are not based upon the so-called end-of-pipe treatment and disposal-based technologies. These alternatives are loosely coined *waste minimization*, *waste-to-energy*, and *resource recovery and reuse* or *recycling*. In previous publications we have referred to all of these simply as *pollution prevention* or P2. Although there may be a better general term or phrase that best describes all of these alternative strategies, we will be consistent with the earlier publications and apply the term P2 again, recognizing that it is not always used in the strictest sense of source reduction. Furthermore, little distinction, if any, is made between the terms waste and pollution. Pollution is waste. In an ideal world, processes would operate at 100% efficiency and consumers would not have any unusable or worn-out products to discard. But the reality is that all manufacturing operations generate by-products that have no value and consumer products have throw-away packaging and limited life spans. These forms of solid waste simply represent lost money stemming from the inefficiencies of industry and the lifestyles of society. This book focuses on recapturing and minimizing the financial losses, which will improve the environmental performances of both industry and the public.

FUTURE AND LONG-TERM LIABILITIES

For industry, when wastes and pollution are created during manufacturing, the generator maintains liability forever. In other words, the ownership of waste can never really be passed on. For example, when we landfill there is always the risk that wastes can breach the landfill liner and contaminate the groundwater. While the owner/operator of the landfill carries responsibilities for remediation in this scenario, the generator of the waste or portion of waste stream contributing to groundwater contamination also has a legal responsibility to share in the costs of remediation. This is what is meant by the terms *joint and several liabilities*. In the United States the federal environmental legislation, that defines this, is CERCLA (Comprehensive Environmental Response, Compensation, and Liability Act).

Following this scenario further, if the contaminated groundwater impacts on off-site property values or perhaps creates a public risk due to chemical or infectious exposures, then the generator faces liabilities from civil actions, which may include direct damages from further remediation, devaluation of property values, pain and suffering and medical bills for injured parties, and/or toxic torts.

Even if the waste entering the groundwater is a nonregulated material, there may be legal exposure. This is especially true when we consider the fact that many chemicals were not recognized as being hazardous or toxic only a few years ago. A good example is ammonium perchlorate (used as an ingredient in some fertilizer and in rocket propellant formulations). For decades this chemical was considered a nontoxic material; however, in the late 1990s studies showed that it has adverse impacts on the human thyroid gland. Companies that inadvertently contaminated groundwater from the use of this chemical during a time period where it was considered safe and not regulated face huge cleanup costs plus toxic torts many years after their operations ceased. Such litigations can cost many millions of dollars in legal fees to address.

Another important concept of our environmental laws is that they are *retroactive*. A company cannot obviate their responsibility for cleanup actions needed because waste disposal or chemical handling practices were considered legal at the time of the operations. And as history has shown us, environmental laws and enforcement become more stringent over time.

These point to the concern that waste handling practices and wastes/pollution forms that are considered within legal and safe limits today may not be in the future. We can view these as future and long-term liabilities resulting from poor environmental performance and also derived from ignoring life-cycle principles.

End-of-pipe treatment technologies and disposal practices not only carry high operating and capital costs, but they invite future and long-term liabilities. These technologies and practices only help to control emissions and wastes to within legal limits of the day, and although the limits protect the public and environment based on current understanding of risks, they incrementally add to the stockpile of waste materials. Since these wastes continue to persist long after disposal, the generator always has a smoking gun sitting around. The only true way to eliminate these liabilities is to eliminate the waste and pollution in the first place, at the source.

THE HIERARCHY OF WASTE MANAGEMENT

Waste and pollution management approaches can be described as strategies. At the municipal level these strategies traditionally have relied on disposal practices (predominantly landfilling and incineration), whereas industry has employed intermediate steps of treatment and stabilization of the more hazardous wastes. Industry strategies are based on *end-of-pipe treatment technologies*, which are more appropriately referred to as *control strategies*, meaning their aim is really to control emissions and wastes to within legally allowable limits of discharge. Both strategies have two disadvantages:

1. They require ongoing costs that are associated with operations and maintenance and with use of energy, and they carry many hidden and indirect costs and liabilities.
2. Releases of infectious, toxic, and hazardous components to the environment continue for many years, posing long-term health risks to the public and endangerment to the environment simply because waste forms are only transformed and not entirely eliminated or completely immobilized.

Waste/pollution management strategies based on prevention strive to eradicate both of the above disadvantages because they eliminate the pollution or waste at the source. They tend to be only partially successful in reducing the first disadvantage because in a number of cases, P2 strategies rely on technology investments which have OM&R (operation, maintenance, and repair costs) as well as other ongoing costs (e.g., labor, energy). But in general, when properly implemented, they are more cost effective than disposal and treatment technologies. Minimization strategies tend to reduce the risks associated with the second disadvantage, but may also offset some of the costs and liabilities noted with the first disadvantage.

When we view the gambit of strategies that are available, a generalized hierarchy based on long-term liabilities or risks associated with waste/pollution management and the costs associated with each becomes apparent. This hierarchy is as follows:

- *Prevention* - This strategy prevents wastes from ever being formed in the first place.

- *Recycling/Resource Recovery/Waste-to-Energy* (R^3WE) - Recycling and reuse of materials, the recovery of certain wastes for reuse (known as *resource recovery*), and the conversion of certain types of waste into useful energy such as heat, electricity, and hot water are strategies which recover and offset costs for overall waste management.

- *Treatment* - When wastes cannot be prevented or minimized through reuse or recycling, then we need to pursue strategies aimed at reducing volumes and/or toxicity. Treatment technologies are processes that focus on stabilization of wastes, reducing toxicity, reducing volume before ultimate disposal, or in some cases creating limited-use by-products.

- *Disposal* - The only other strategy available is disposal. Waste disposal practices are integrated into the environmental management strategies of all municipalities, are integral to most manufacturing operations, and quite often are among the highest direct cost components. From a business standpoint, it is the least desirable strategy and one that can be directly addressed by waste minimization and P2 practices.

Figure 1 illustrates the hierarchy in a graphical format by comparing the relative risks and costs associated with each strategy. Strategies that reduce or eliminate wastes before they are even created are preferable to those that incur ongoing expenses for treating and disposing of wastes that are generated continuously because long-term risks and costs are lower.

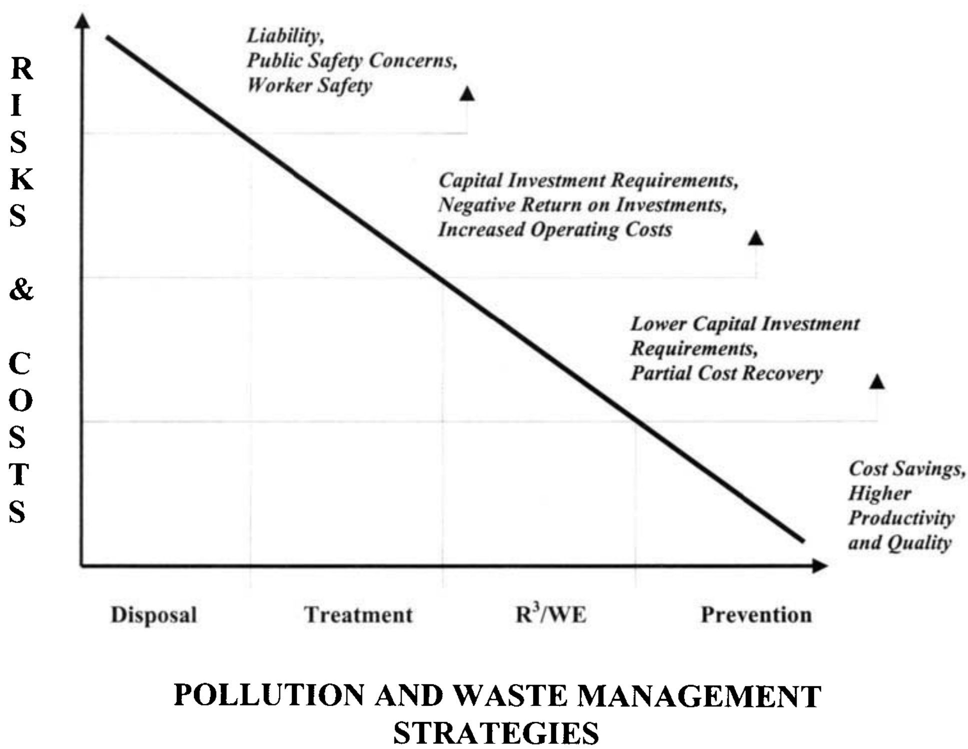

Figure 1. Hierarchy of pollution and waste management strategies.

Prevention has been more successfully applied and understood at the manufacturing level than at the municipal, because companies can readily achieve direct cost savings. P2 strategies have proven to be advantageous since the practices are more cost effective than control-based technologies; hence, companies save money in meeting their environmental obligations.

More recently, some companies have begun applying principles of *designing for the environment*, whereby new products entering the marketplace are more environmentally friendly and generate less solid waste, are biodegradable, or can be readily recycled. This approach is based on life-cycle principles, which we will get to shortly.

At the municipal level, pollution prevention requires major changes in consumer patterns and lifestyles. The general public, while genuinely concerned and knowledgeable about the environment, has not received widespread education on preventive techniques, nor are there many choices in selecting more environmentally friendly forms of consumer products from among the items that support our lifestyles. This leaves municipalities with the option of R^3WE. We may look at the hundreds of millions of tons of solid waste generated each year worldwide as an enormous and costly waste disposal effort that continues to deplete our natural resources and requires enormous ongoing expenditures, or we may view these wastes as a virtual gold mine of resources from which useful by-products and energy can be recovered. By the same token, resource recovery, WTE (waste-to-energy), and recycling strategies do not entirely eliminate solid waste disposal problems, and further, they only make sense when such strategies are economically viable.

Figure 1 in some ways is an oversimplification. In terms of capital and direct operating costs, pollution control, treatment, and disposal options generally appear more cost effective than some high-level investments into so-called *green technologies*. A green technology is one which is considered environmentally friendly, but may carry a high investment. As an example, the investment in converting from a coal-fired electricity generating plant to natural gas is seemingly hard to justify from an economic standpoint, and indeed some case-specific studies show the investment to be unattractive. However, many investment studies often overlook the likelihood of long-term and future liabilities. These are rarely given sufficient attention in investment strategies that focus on pollution and waste management.

THE PRINCIPLES OF LIFE CYCLE

The term life cycle refers to *cradle to grave*. If we view any product as a living entity, that product has a birth, a period of life in society, and then death.

Historically, science and technology have focused on new ideas, concepts, products, and their applications, with the objective of giving a useful life to products that serve our needs. But in the past we have given little thought to the demise of these entities. By ignoring the end cycle, we lose sight of the fact that the natural resources that have gone into making products are not infinite, and that on a worldwide basis the rate at which we consume products with a throw-away mentality is unsustainable. Furthermore, we do long-term and even irreparable damage to our environment by introducing more and more waste and pollution into the environment. By the same token, when we rely on inefficient technologies to mass-produce products, we continually waste more resources and generate more pollution.

Life-cycle principles give equal consideration to all three phases of existence of a product, including how the product is made. These principles are not new, and indeed have been around for decades, but we are only now getting around to learning how to apply them effectively in designing new products and more efficient technologies. This is known as *design for the environment*.

We must recognize that since we do not live in a utopian society, economics overshadows many decisions. For industry, sustainability and growth are tied to profitability. To sustain businesses and to maintain or grow profit margins, among other things companies must meet their environmental obligations in a cost-effective manner. Few companies, if any, will spend more to protect the environment than is necessary beyond their legal requirements. Some industry readers may disagree with this statement and point out that there are companies that indeed "go beyond compliance." But even these businesses are in fact relying on economic forces that enhance their profitability. Companies that allocate more funds toward exceeding environmental performance reap financial benefits from such areas as public opinion and investor confidence that provide them competitive advantages. These impacts ultimately result in positive effects on profit margins.

With this logic then, life-cycle principles are most effectively applied today as an economic instrument, which is called *life-cycle costing* or LCC. LCC is applied to life cycle costing analyses (LCCA) as a basis for comparing the economic attractiveness of different environmental management strategies or technology investments. In other words, instead of changing the product design (which ultimately is what needs to be done to really improve the environmental performance of society on the whole), LCC tools are being applied more effectively today in making decisions on whether simply meeting compliance with controls is less or more costly than preventive or minimization technologies.

As an example, consider a steelmaking plant. The two technology routes for steel making are the basic oxygen converter and the electric arc furnace (EAF). The basic oxygen furnace (BOF) may be described as a "dirty" technology, producing significant amounts of air pollution, and therefore requiring many sophisticated and costly air pollution controls. Although the EAF steelmaking process is more environmentally friendly, it requires a very high capital investment. An LCC analysis will enable a comparison of the costs for each of these technologies over the life of the plant. By comparing all the costs components such as capital equipment, OM&R, energy requirements, productivities between the technologies, and the costs for controls or the savings from eliminating certain controls, as well as the final scrap value of the equipment, we can determine which is the least life cost or most attractive investment option. With both technologies we may meet legal requirements of safe air emissions, but only one of these is likely to be attractive from a financial standpoint based on local economies and the long-range business plans of the company, as well as the reduction of long-term risks associated with environmental management. LCC tools and their application to developing pollution and waste management strategies are discussed later in this book.

COSTS OF ENVIRONMENTAL MANAGEMENT

The costs for environmental management fall into four groups, which we have referred to as tiers in previous publications on P2, namely:

- Tier 1. Usual and normal costs
- Tier 2. Hidden and indirect costs
- Tier 3. Future and long-term liability costs
- Tier 4. Less tangible costs

These categories are referred to as tiers because they represent layers of costs that we need to unveil in order to truly understand the life cycle costs associated with the level of environmental performance they target to achieve.

Usual and normal costs are direct costs for compliance. These are easy to define for control-based technologies and most companies have a clear understanding of them up front. They generally are well tracked, or at least should be. Examples include capital equipment costs (e.g., costs for electrostatic precipitators, scrubbers, wastewater treatment equipment), the costs for operating those controls (e.g., manpower, utilities, such as water and electricity), OM&R costs for controls, operator training, waste transportation and disposal costs such as landfill tipping fees, and a number of other items that are recognizable in any capital intensive engineering project. Examples are provided in Fig. 2. Such cost components are easy to define in a LCC analysis and are the group of data most often relied upon in comparing life-cycle investment options between competing alternatives. However, they do not provide a complete or even a majority accounting for the true costs associated with environmental management.

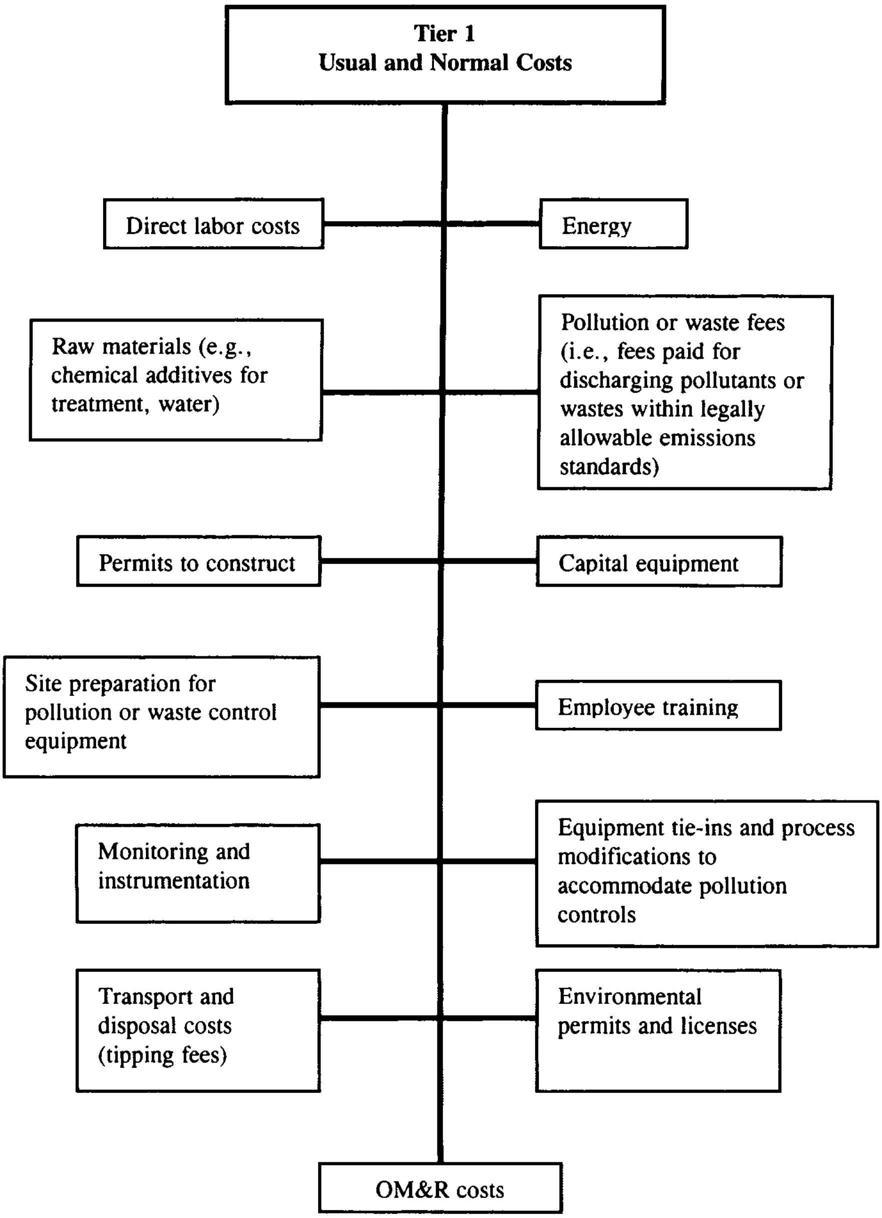

Figure 2. Examples of easily tracked usual and normal costs.

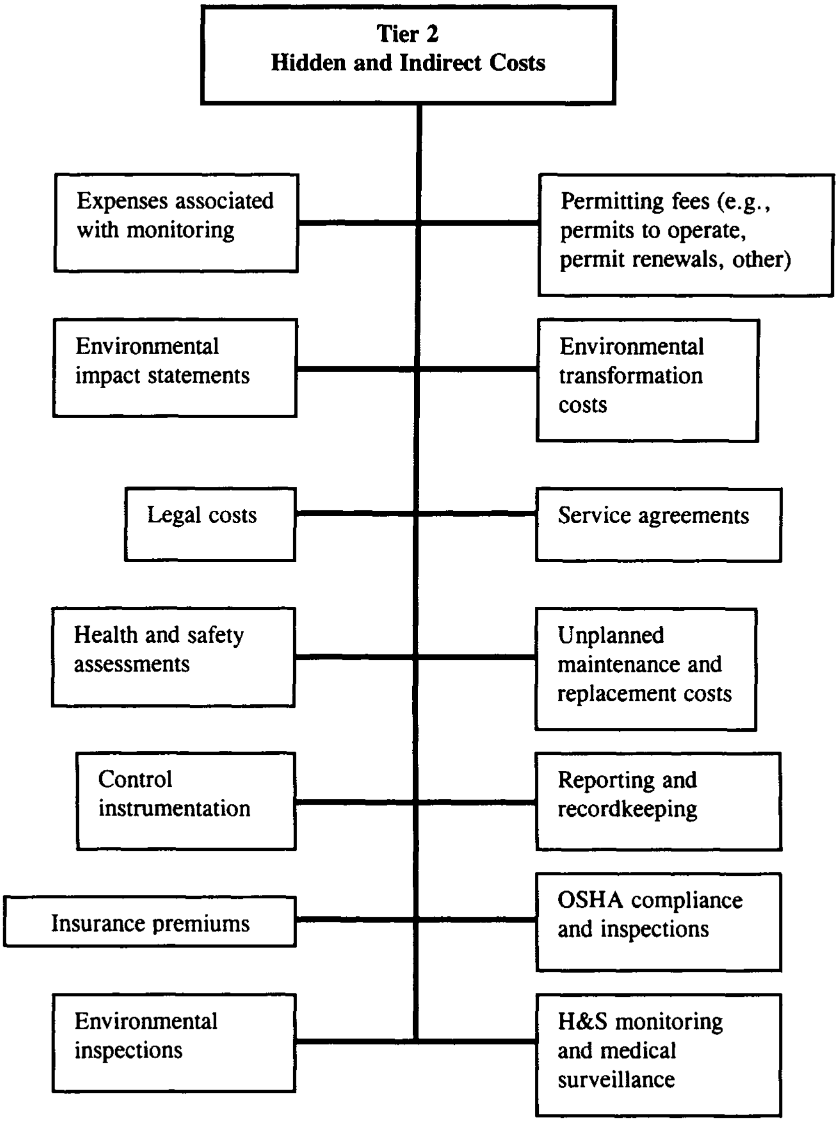

Figure 3. Examples of hidden and indirect costs not always tracked.

Hidden and indirect costs include those of monitoring (e.g., manpower, controls, lab support), permits to operate controls and for point source discharges, permits and licenses for waste storage and treatment, environmental impact statements, service agreements for transport, disposal, and instrumentation/equipment maintenance, manpower costs for recordkeeping and reporting, and insurance premiums to cover fire, explosion, and environmental damages that might occur from the operations.

Among the hidden components are environmental transformation costs. These are the costs associated with transforming a pollution or waste problem from one form to another. For example, controlling an air pollution problem simply transforms the form of the pollution to a water and/or solid waste problem. There are both tier 1 and tier 2 costs associated with the transformation technologies. Some companies are sensitive to the tier 2 components, but many are not. They certainly are not examined closely enough when selecting many environmental management strategies, yet they can play a major role in an investment decision when LCC tools are applied. Examples of tier 2 costs are given in Fig. 3. A useful exercise for the reader is to add on to this list as it certainly is not all-inclusive.

Some skeptical readers may argue that some of the components listed in Fig. 3 are small and may be ignored. However, that depends on the magnitude of operations and whether or not they are recurring throughout the life of an operation.

Future and long-term liability costs (tier 3) are among the hardest for many companies to account for because they are based upon future events. Cost components in this group depend upon both the level of environmental performance a company achieves, and the effectiveness of the environmental strategies employed. Examples are listed in Fig. 4. Among these examples, only inflation is a component that we might be able to predict with some degree of confidence and can factor into a LCC analysis when comparing options in terms of investment costs. But other costs in this tier depend on the likelihood of certain events occurring.

Certainly, if a company consistently shows poor environmental performance, the probability of some of these costs materializing and developing into long-term liabilities and ongoing remediation costs is high. But even when companies are consistently within compliance requirements using control-based technologies there is the potential for future exposures to some of the items listed in Fig. 4 since waste forms are never truly eliminated. Tier 3 costs can arise from the risks of relying upon certain technologies and strategies that, although enable companies to achieve consistent environmental performance from a regulatory standpoint, pose a future financial exposure from a scenario that is more likely than not to occur. As example; if landfilling is relied upon to dispose of hazardous wastes, the potential exists for the liner to be breached and contaminate the groundwater, resulting in offsite and third-party damages. Or if a manufacturing operation relies on a chemical component that is toxic, workers could sue a company for chromic exposures resulting from their handling of the material over their years of service. This in turn could result in an insurance company raising premiums for medical coverage. If these types of scenarios are more likely to occur than not, or simply stated, have a reasonably high probability of occurrence, then there is a strong basis for choosing pollution prevention and waste minimization strategies.

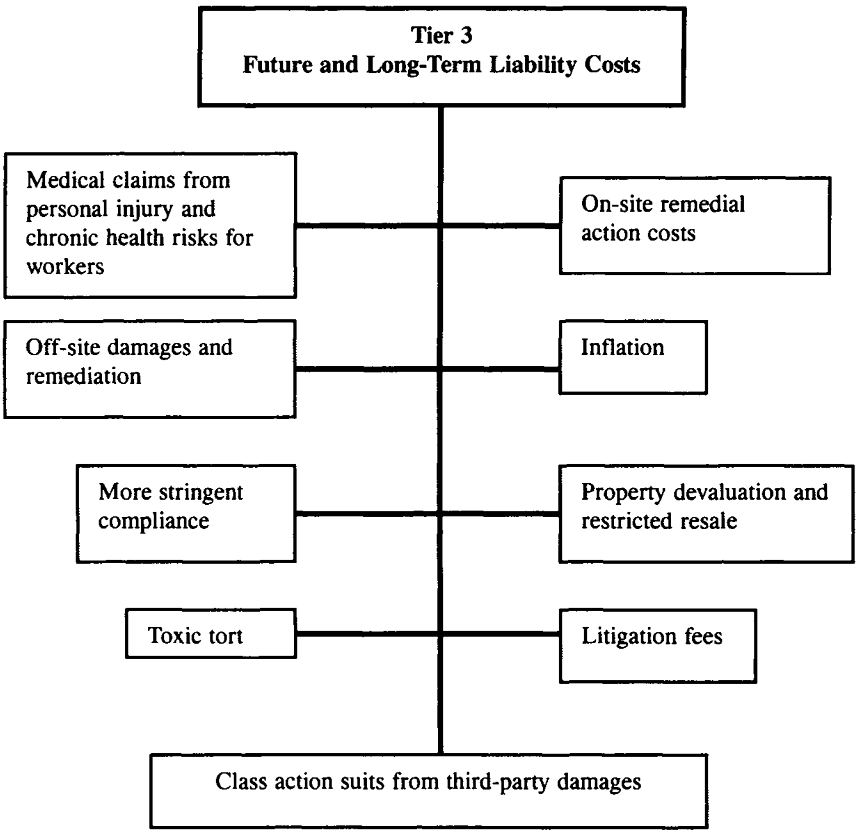

Figure 4. Examples of costs related to future events (i.e., long-term and future liabilities).