Chapter 3

Technology and Waste Reduction Decisions

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INTRODUCTION

The goals of this chapter are to discuss factors affecting the use of technology for waste reduction and to examine the scope, diversity, and applicability of waste reduction practices.

No attempt is made to give a comprehensive description of proven or potentially effective waste reduction methods for different industries, processes, or wastes. Not only are there many thousands of industrial processes and wastes, but there are also important plant-specific constraints of both a technical and economic nature to waste reduction. Examples of successful waste reduction methods, are instructive, but technologies that are effective in one case may not be applicable for reduction of other hazardous wastes.

It is important to see waste reduction as part of the broader picture of industrial product and process improvement, modernization, innovation, and expansion, not simply as a means to environmental protection. Waste reduction is more accurately thought of as being related to, dependent on, and a contributing cause of all those steps that a company takes to remain competitive and profitable. It is just as sensible to ask whether, and to what degree a company reduces hazardous waste as it is to ask how much R&D, energy conservation, or productivity improvement the company carries out, what its accomplishments have been, and how these factors affect competitiveness and profitability.

The phrase *waste reduction technology* in itself can be misleading; the phrase deals more with a goal of technology than with its technical content. Some actions taken toward this goal may be related solely to waste reduction, but most will be intimately related to production technologies, activities, or materials which have some capability for reducing waste without that being their primary function—that of making a profitable product that satisfies customer requirements. Waste reduction methods, therefore, encompass a vast array of techniques and actions that are useful and beneficial in ways that frequently go beyond waste reduction. Waste reduction can be thought of as a criterion to assess almost any industrial production technology rather than as a unique technology, a machine, or even a field of expertise.

Two major implications arise from this conclusion. First, the selection of waste reduction technology requires a great deal of knowledge about the specific waste generating situation. This expertise has little to do with pollution control technology but everything to do with production processes, plant operations, and end products. The worker on the plant floor, the manager of the plant, the design engineer, the laboratory researcher, the purchasing agent, and everybody else who has a hand in production can see or explore opportunities to reduce waste—if they have been made aware of the need to do so. Waste reduction techniques run the spectrum from simple changes in day-to-day operations to wholesale redesign of process technology or end product. Therefore, even though waste reduction is generally seen solely as an environmental protection activity, it is not. Waste reduction serves environmental protection goals, but it is fundamentally an improvement in production with beneficial effects that may be widespread.

People outside of industry who are interested in waste reduction and have experience in the environmental area may take a narrow view of waste reduction; frequently they neither have familiarity with front-end industrial production technologies and techniques, nor with their limitations and opportunities. Conversely, *production* people may not have paid much attention to the environmental developments that have motivated the call for waste reduction. Therefore, making waste reduction a goal, motivating and rewarding behavior that reduces waste, and setting up an organizational structure that encourages thorough examination of waste reduction opportunities are just as important as selecting or designing waste reduction hardware.

Second, whenever something is done for the purpose of waste reduction, there are likely to be other consequences; these maybe just as significant, if not more so, than waste reduction itself. For example, worker productivity may increase as a result of one waste reduction action; product quality might decrease as a result of another action, For each plant, there are costs, benefits, and site-specific constraints to waste reduction which cannot be completely predicted from experiences at other plants. The feasibility of waste reduction is embedded in the entire production system in which it must take place.

What all this means is that waste reduction activities are very open-ended and very difficult to describe or assess comprehensively. A further implication is that certain activities (discussed in detail elsewhere) often related to technology use and assessment are not easily undertaken for waste reduction. These include: 1) forecasting, even approximately, how much waste reduction is technically feasible for the Nation, industries, or a specific operation; and 2) suggesting how the government might require companies to achieve a given level of waste reduction,

On the other hand, when the production context and purpose of waste reduction are understood, it becomes clear that there are numerous opportunities to reduce waste. How much waste reduction is achievable depends both on how much *attention* is given to it and on the amount of waste reduction technology that exists. Human factors, organizational structure of companies and government policies all have critical roles in waste reduction decisions. Success in reducing waste begins with human perceptions of need and requires an examination of a myriad of opportunities.

THE SPECTRUM OF APPROACHES

Five Broad Approaches to Waste Reduction

Developing a scheme to group the technical approachs to waste reduction is important because the range is so great, There are several ways to do this. OTA has chosen a scheme that emphasizes *opportunities and approaches* for waste reduction rather than types of industries or wastes, Five broad approaches that are applicable to almost all industrial operations have been used.[1] The following list gives these approaches in order of decreasing importance to the respondents to OTA's industry survey (see app. A).

Approach 1: In-Process Recycling

Potential wastes, or their components, can be returned for reuse *within existing operations* (see box 3-A). This approach is more applicable to liquid waste streams than to solids, sludges, or gases. Recycling as a means of waste reduction is an integral part of the production process.[2] For example, at a Du Pent plant making Freon, hydrochloric acid waste was eliminated by installing a $16 million conversion unit to change anhydrous hydrogen chloride into chlorine, which is recycled back into the process, and hydrogen, which is used as a fuel in the plants Carrier Air Conditioning Co. collects

[1] For example, the five approaches can be applied to farming and mining. Pesticide runoff can be reduced by using a biological rather than a chemical method of pest control. Changing mining operations can prevent leachate from polluting nearby surface water.

[2] This should not be interpreted too narrowly. In some cases, such as a plant that produces a chemical, recycling a waste or its component is physically a part of the operation; that is, pipes can move waste from one end of the plant to a point near the front end in a closed-loop system. However, in other cases such as paint stripping or vehicle maintenance, recycling of a solvent or motor oil may take place within the same building, at a separate recycling unit, with the recycled material moved periodically for use elsewhere within the building, just as a purchased new raw material would be.

[3] The examples cited in this chapter come from a number of recent reports, conference proceedings, and books referenced elsewhere in this report.

Box 3-A.—Waste Reduction by In-Process Recycling: Countercurrent Rinsing and Recycling of Caustic Soda From Thread Mercerization

In the late 1970s, a French textile company found that it could reduce the amount of caustic soda discharged in wastewater by altering its rinsing process following mercerization to permit recycling of the soda. (In mercerization, thread is immersed in a caustic soda bath containing a wetting agent.) The company's original technology followed mercerization by rinsing the thread in three water baths that were discharged after use. The waste reducing technology replaces these baths with a stream of running water, Soda gradually concentrates in the rinse water until it is efficient and cost-effective to employ an evaporator that will elevate the soda concentration sufficiently to allow the soda to be recycled back into the mercerizing process, along with the wetting agent it contains.

The new technology reduces both the volume and the amount of hazardous waste generated, per unit product. In the old method, 360 kilograms (kg) of soda in 80 cubic meters (m^3) of wastewater were created as waste for each ton of thread mercerized. With the new technique, only 100 kg of soda in 13 m^3 of water are generated. The new process required investments of *1,430,000* French francs, 330,000 francs more than the old process, but is cheaper to operate: 1,320 francs/ton of thread mercerized using the new process versus 2,000 francs/ton using the old process. The waste reducing process requires less energy (15.7 gigajoules (GJ)/ton of thread vs. 19.5 GJ/ton under the old method) and less raw materials (only 170 kg of pure soda and 3.5 kg of wetting agent are required per ton of thread as opposed to 430 kg soda and 8.5 kg wetting agent required for the old process.) It also requires fewer man-hours to operate.

SOURCE: United Nations, Economic Commission for Europe, *Compendium on Low- and Non-Waste Technology* (Geneva, Switzerland: 1981), monograph #26.

and recycles the overspray in its painting operations. Diversified Printing Corp. and Donnelley Printing Co, recover and use 86 and 87 percent respectively of the organic solvents in inks,

Major limitations to in-process recycling include:

- possible significant differences between recycled and virgin materials and the inability to use waste that maybe chemically different than the raw materials,
- highly fluctuating market prices for virgin raw materials,
- the greater applicability to continuous vs. batch processes,
- amounts that are too small to justify investment for new equipment, and
- the need in some cases to perform costly steps to separate components before some of the waste can be recycled.

Although in many cases in-process recycling does not require substantial testing and development or capital investment, in other cases it does. This waste reduction option is most closely related to pollution control, which in part explains its wide use (see below).

Approach 2: Process Technology and Equipment

Significant changes in the basic technology and equipment of production, including modernization, modification, or better control of process equipment may result in reduction of waste (see box 3-B). Such reduction may also come about through major changes in technology (e. g., adopting a different way of making a commodity chemical or refining a metal-bearing ore may reduce a company's waste). For example, 3M replaced a chemical process to clean flexible metal electronic circuits with a strictly mechanical process. Professor Raymond Young of the university of Wisconsin (Madison) has invented a new pulp-making process that does not use sulfites and has no sources of air or water pollution; it is in the pilot-testing stage, Lancy International designed a new process for Elkhart Products Inc. to remove oxide and passivate (render the surfaces chemically inactive) pipe fittings by using nonhazardous solutions instead of a cyanide dip and a chromic acid dip, Amoco Chemicals Corp. modified a manufacturing process and reduced its ignitable and oily wastes by 60 to 70 percent.

Box 3-B.—Waste Reduction Through Process Technology and Equipment Changes: Plastic Media Paint Stripping

Hill Air Force Base in Ogden, Utah, has developed an alternative technology for stripping paint from aircraft and ground support equipment. Paint is conventionally stripped from aircraft and ground support equipment with a solvent, typically an acidic methylene chloride solution, followed by scraping, washing [contaminating thousands of gallons of water), hand sanding, and buffing. Chemical stripping is expensive and time-consuming, releases noxious fumes into the workplace, and generates large amounts of hazardous waste. The alternative removes paint with modified conventional sandblasting equipment using recoverable plastic beads in lieu of sand. Waste from this process is only pulverized paint; the beads mixed with the paint dust are easily recovered for reuse in the process.

The plastic media technology has some limitations. It does not strip rain erosion coating, can damage soft cadmium coating and windows, and care must be exercised in stripping carbon composite, fiberglass, and lightweight aluminum surfaces, However, these were considered minor limitations by Hill AFB.

Mechanical stripping technology may be transferred to a wide variety of operations that currently clean and remove paint from metal objects with solvents.

Summary of resulting changes (for stripping one F-4 aircraft):

	Chemical stripping	*Plastic media*
Waste generation:		
Hazardous solid	9,767 lb sludge	320 lb dry waste
Wastewater	200,000 gal	0
Waste management costs:		
Hazardous solid (all trucked to California, cost $200/ton)	$ 967	$ 32
Wastewater treatment	$1,485	0
Investment	unknown	$647,389[a]
Manhours required	341	39
Raw materials cost	$5,422	$ 346
Energy costs	$ 231	$ 127

[a]For stripping hanger: payback is just over 1 month based on operation cost savings.

SOURCE: DOD Environmental Leadership Project, *Industrial Processes to Reduce Generation of Hazardous Waste at DOD Facilities,* Phase 2 Report: Evaluation of 18 Case Studies, prepared by CH2MHill (T.E. Higgins), July 1985, pp. 3-29 to 3-48.

Major changes often require substantial technological development and perhaps capital investment. It may be easier to make them when redesigning an entire process or designing a new plant or operation rather than as a modification to a part of an operating system.

However, equipment and technology changes do not necessarily require a major process overhaul, Dow Chemical reduced both waste and costs in a crude-product drying system when it installed a computer and on-stream analyzer to adjust the concentration drying agent in the flow, previously, sampling and lab analysis of the flow was done six times daily and a drying agent was added by hand. The new automated system is able to keep the ratio of drying agent more nearly optimal and therefore reduced the amount of drying agent input material required by 37 percent.[4]

Approach 3: Plant Operations

Better plant management or housekeeping can significantly reduce waste (see box 3-C). Examples of operation changes include:

- improvements in ancillary plant operations such as better predictive and preventive maintenance;

[4]Ryan Delcambre, Dow Chemical, "Dow Chemical Hazardous Waste Minimization and Incineration,' paper presented at a League of Women Voters conference, *Waste Reduction: The Ongoing Saga*, Woods Hole, MA. June 4-6, 1986.

Box 3-C.—Waste Reduction Through Changes in Plant Operations: More Efficient Materials Handling

Since 1982 Borden Chemical Co.'s Fremont, California, plant has reduced organics in its wastewater by 93 percent through four separate changes in its handling of phenol and urea resins, as follows:

1. Borden altered its method of cleaning the filters which remove large particles of resinous material as the resin product is loaded into tank cars. They began collecting the rinsewater instead of sending it down the floor drains and into the company's onsite wastewater treatment plant. This rinsewater can be reused as an input in the next batch of phenolic resin.
2. When loading urea resin, they began reversing the loading pump at the end of each load so that resin on the filters would be sucked back into the storage tank and would not be rinsed out as waste.
3. The company revised rinsing procedures for reactor vessels between batches. Previously, 11,000 to 15,000 gallon chambers had been cleaned by filling them with water, heating and stirring the water to remove resin residues, and then draining the rinsewater into the plant's wastewater. The plant now uses a two-step process. A small, first rinse of 100 gallons of water removes most of the residue from the containers. Then a second, full-volume rinse is used to complete cleaning. The first 100 gallons of rinsewater is reused as input material for a later batch of resin. Water from the second rinse is discharged as wastewater but has a lower phenol concentration than the previous volume of wastewater.
4. Procedures for transferring phenol from tank cars to storage tanks have been altered. Formerly, when the hose used to transfer the phenol from car to tank was disconnected, a small amount of phenol dripped down the drain—enough to cause problems given the strict regulatory limitation for phenol. Now, the hose is flushed with a few gallons of water to rinse the last bit of phenol into the storage tank.

In addition to greatly reducing wastewater volumes, these changes have eliminated most of the hazardous solid wastes generated by the resin manufacturing processes because the company was able to discontinue use of the onsite evaporation pond to treat these wastewaters.

SOURCE: David Sarokin, et al., *Cutting Chemical Wastes* (New York: INFORM, 1985), pp. 97-102.

- better handling of materials to reduce fugitive emissions, leaks, and spills;
- changes in methods of cleaning equipment to avoid use of hazardous materials;
- better monitoring of process equipment for corrosion, vibration, and leaks;
- more automation of processing;
- separation of waste streams to facilitate in-process recycling;
- use of covers on tanks and other actions to reduce vapor losses; and
- more use of sensing devices to detect and prevent nonroutine releases of wastes,

For example, the Stanadyne Co. 's metal plating operation reduced waste by int reducing a pause into the machine that moves parts in and out of tanks; this allowed dragout solution to drip back into the process tank rather than pollute the rinsing tank. Exxon Chemical Americas installed floating roofs over its tanks of volatile solvents, greatly reducing waste emissions. Daly-Herring Co. replaced its single baghouse system with two separate systems for two production lines of different pesticides so waste dust from each could be returned t o production. As these examples show, there are many simple, low-tech opportunities to reduce waste by examining plant operations. Often only parts of waste streams are reduced, but implementation is typically quick and inexpensive. Motivated workers are the key to finding and exploiting these opportunities.

Approach 4: Process Inputs

Changes in raw materials, either to different materials (e. g., water instead of organic solvents) or materials with different specifications (e.g., lower levels of contaminants) may reduce waste. For example, Scovill, Inc., replaced the solvent 1-1-1 trichloroethane with a water soluble cleaner for decreasing applications. Riker Laboratories replaced organic solvents used to prepare coated medicine tablets with a water-based solvent and also used different spray equipment. Pilot studies have also shown that process input changes may be used to reduce wastes in mining. Nontoxic reagents have been substituted for cyanide compounds in the processing of copper ores; similarly, alkalinity of processing reagents can be maintained by using reagents less toxic than ammonia, for example lime.[5]

Frequently, changing raw materials is associated with making changes in process technology and equipment or in the composition of the end product. In box 3-D is an example of changing printing inks. Cleo Wrap, a relatively large company, made a major commitment over several years, developing a family of new inks and changing printing equipment to accept the new inks. Smaller companies may be dependent on their vendors for changes in raw materials, and vendors may not be able to make changes for waste reduction purposes unless large waste generators help them develop these new products. When the waste generators are their own raw materials suppliers, changes are much easier.

Box 3-D.—Waste Reduction Through Changes in Process Inputs: Substitution of Water-Based Inks for Organic Solvent-Based Inks in Printing

In 1986 Cleo Wrap, the world's largest producer of Christmas gift wrapping paper, completed its conversion from organic solvent-based inks to water-based printing inks in all its operations. Organic solvent-based inks required organic solvents for cleaning presses; water-based cleaning solutions and soap will now do the job. Because Cleo Wrap is so large and manufactures such a variety of color designs, ink changes and press cleanups are frequent and the amount of organic solvent being used was substantial. In 1984, the last year of the 6-year phase-in of the water-based inks, Cleo Wrap was reporting 133,555 kilograms of ignitable hazardous waste. Annual hazardous waste disposal costs were $35,000. Cleo Wrap now plans to seek status as a small quantity generator.

This substitution has had several benefits. It has made it possible for Cleo Wrap to remove all eight of their underground storage tanks, to eliminate all above ground solvent storage, to reduce or eliminate fire hazards, to seek lower fire insurance premiums, to eliminate their ignitable hazardous waste holding area, and to eliminate their hazardous waste disposal costs.

This raw materials substitution required some equipment changes and retraining of employees to work with the water-based technology because printing sequencing and drying techniques are very different. The change also required Cleo Wrap to persuade their ink suppliers to develop a full range of water-based ink colors that did not exist when the company undertook the change in 1978.

SOURCE: Award presented at Governor's Conference on Pollution Prevention Pays, Nashville, TN, Mar. 4-6, 1986.

Approach 5: End Products

Changes in the design, composition, or specifications of end products that allow fundamental changes in the manufacturing process or in the use of raw materials can directly lead to waste reduction. For example, 3M reformulated a product to use a nonhazardous organic ma-

[5] U.S. Environmental Protection Agency, *Report to Congress: Wastes from the Extraction and Beneficiation of Metallic Ores, Phosphate Rock, Asbestos, Overburden from Uranium Mining, and Oil Shale, EPA/530-StV-85-033* (Washington, DC: Office of Solid Waste, Dec. 31, 1985), p. 3-5.

Box 3-E.—Why Companies Fear Adverse Affects on Product Quality Resulting From Waste Reduction

Monsanto reformulated a specialized industrial adhesive so that hazardous particulate remained in the product, thus eliminating the need to use and dispose of filters and particulates as waste. However, the company then had to convince its customers that the particulate matter formerly removed by the filters could remain in the product without affecting its adhesive qualities. From the time the company researchers came up with the idea of reformulating the product, 2 years of effort by Monsanto's Research and Marketing Divisions was required before the reluctance of the purchaser to accept a different product was overcome and the change could be made.

SOURCE: David Sarokin. et al., *Cutting Chemical Wastes* (New York: INFORM, 1985), p 89

terial instead of a metal alloy in its manufacture, thus eliminating a specific cadmium-containing hazardous waste.

This approach is difficult because of constraints imposed on the product by the customer orb} performance specifications (see box 3-E). Implementation may require significant and costly changes i n the production tech nology or the raw materials. For these reasons, this is the most difficult waste reduction approach to use.

A variation on this approach was used by Dow Chemical when it changed the way it *packaged a* product. A wettable powder insecticide, widely used in the landscape maintenance and horticulture business, was originally sold in 2-pound metal cans which had to be decontaminated prior to disposal, thereby creating a haza rdous waste. Dow now packages the product in 4-ounce water soluable packages which dissolve when the product is mixed with water for use.[6]

[6]Delcambre, op. cit

Selection and Implementation of Waste Reduction Approaches

The tendency for industry to concentrate on in-process recycling and plant operations can be explained in several ways. First, recycling and plant operation changes are add-ens. They are similar to end-of-pipe techniques that engineers use to achieve conventional pollution control goals. Thus, while these actions are part of production, they do not tend to involve major changes in process technology and equipment.

Second, recycling and plant operation changes are also often the least expensive option, rarely requiring large capital investment and usually bringing immediate returns. Although recycling can be costly to set up, the benefits of using the recycled material are relatively certain and easy to calculate. For example, the consequences of using a recycled material instead of a virgin material can be figured out in a straightforward way, such as by making trial runs with the recycled material to check the processing parameters and product quality.

Third, these approaches are easy for engineers and plant workers at all levels to identify and are relatively easy to implement. They are also unlikely to disrupt plant operations and risk product quality and, therefore, require little attention from senior management. In fact, because these approaches are so simple, management may not track them. And because they are easy to implement, they are difficult to document and unlikely to be emphasized in the literature. In sum, changing plant operations and in-process recycling usually poses little risk because neither the company's product nor its processes are significantly affected.

Changing process technology, raw materials, and end products may require intensive engineering efforts and even R&D, may pose possible risks for product quality and customer acceptance, and eventually may call for significant capital investment. Moreover, the effectiveness of these changes in terms of waste reduction may not be easily predictable. Most environmental engineers or plant operating engineers have neither the training and expertise nor the authority to implement such actions. Nor are these opportunities apparent to plant workers. To implement these kinds of changes, engineers and scientists who have been concerned solely with industrial processes and technology or with product development and design have to be given new responsibilities and have to be educated and motivated to implement change for—but not restricted to—waste reduction. Company management has to become involved, either directing the attention of such people to waste reduction, making it a major criterion for success of company R&D efforts, or getting outside technical assistance to implement waste reducing changes. Older plants and mature industries are especially likely to have significant problems and face high costs for waste reduction actions of this kind that involve significant changes in technology, major equipment, and raw materials.

Why, then, are process technology and equipment changes ranked second, both by industries in the OTA survey and in the literature? *In spite of the difficulties and risks, waste reducing process and equipment changes are sound economic investments for many companies and can improve both their efficiency and profitability.* Both the OTA survey and the literature sampled extend across a broad cross-section of industry, representing many industry types, not just the mature industries which can find process changes difficult. The popularity of process changes indicates strongly that serious, front-end waste reduction is possible in a wide variety of industries.

The Investment-Uncertainty Barrier

The fact that waste reducing process and equipment changes are frequently sound economic investments is indicated by the results of OTA's industry survey and by economic data in the literature, OTA asked respondents in 99 companies to rank nine types of obstacles to waste reduction as to whether they were "usually, " "occasionally," or "rarely" a problem in their operation (see app. A). Capital costs were ranked as only an "occasional" obstacle. Waste reduction investment documented in the literature (see discussion later in this chapter) often provides economic data on costs and savings, which are virtually always very favorable and illustrate a wide variety of ways in which waste reduction measures can provide high return on relatively small amounts of capital. While such opportunities may not be available to all companies at all times, it is clear that a large amount of waste reduction is possible and has been undertaken by companies without large amounts of capital and with high returns on investment.

This is true now, when most companies are in the early stages of waste reduction. However, as interest in or pressure for waste reduction increases, a firm will exhaust the obvious, simple, cheap, and quickly implemented ways of achieving this goal. The amounts of capital which must be invested to achieve further waste reduction may increase. At the same time, certainty about the return on those investments is likely to decrease. Additional waste reduction efforts will increasingly require changing the fundamentals of processes and product design in new and untried ways. These more complex measures are dependent on intimate knowledge of specific, often unique, details of the plant's technology, operations, and products. Companies therefore cannot rely on outside information and the experience of others but must take the risks of experimentation and implementation themselves.

For most generators, a combination of greater resource requirements and greater uncertainty about payoff become barriers to further waste reduction at some point. However, determining when this point has been reached may be a matter of perception and opinion. When someone says his company "can't do any more waste reduction," he maybe thinking of waste *management* approaches, or he may mean the company has exhausted the obvious, simple, and cheap techniques to reduce waste. To go further would require more time and money, and willingness to invest despite uncertainty about the waste reduction outcome. Moreover, some firms have trouble not only in implementing basic production technology advances but even in *finding* information about technical approaches. In such cases, lack of attention to waste reduction may be a symptom of a larger problem,

Older, troubled manufacturing industries, in particular, may encounter the investment-uncertainty barrier early on. For many smaller companies with few technical resources and with difficulties in raising capital, this barrier may be virtually insuperable. To overcome the investment-uncertainty barrier and pursue what might be the most effective means of waste reduction, industry may need strong motivation, either from within (e. g., greater tangible management support) or from outside (e. g., direct government assistance).

As will be discussed later, it is extremely difficult to estimate waste even approximately reduction potential. Hence, whether a plant-spec ific barrier can be reasonably overcome or whether some true upper limit to waste reduction has been reached—based on exploration of all approaches—is very difficult to resolve. It is difficult for the company's management and even more difficult for someone on the outside, On the other hand, the evolution of most product ion operations based on such objectives as modernization, innovation, and new product development will provide a number of added opportunities for waste reduction. But, as stated earlier, such opportunities are fewer, in mature industries.

In some sense, the evolution from simple and cheap to complex and costly means to achieve waste reduction may be happening in the Nation as a whole. This is a speculative statement because not every industrial plant is starting waste reduction at the same time or proceeding at the same pace. However, because we have had a voluntary approach to waste reduction, industrial efforts probably have concentrated on the easiest approaches to waste reduction, although some firms have progressed further. Many firms may not have had enough time yet to implement fully even the easiest forms of waste reduction, much less to consider or examine more costly approaches. Government policies and programs have not yet paid much attention to waste reduction, information and technology transfer are in early stages, and many industries are still just beginning to undertake waste reduction as an end in itself. Nor has waste reduction become a major issue for the public. This state of affairs underlines an important fact: waste reduction's subordinate position to pollution control and to the more traditional imperatives of the production system has resulted in **suboptimal** levels of waste reduction.

ILLUSTRATIONS OF WASTE REDUCTION

A Growing Literature

Waste reduction is discussed in a rapidly expanding literature from the United States and several European nations. Most publications present case study examples of successful waste reduction to illustrate its feasibility. The literature does make a case for waste reduction—both for its desirability and for its feasibility—but it is probably not very useful to other companies in their waste reduction efforts nor is it of much help to those outside of industry in assessing the transferability and limitations of the techniques discussed.

There are several reasons for the lack of usefulness. First, few accounts go into enough detail to give a thorough understanding of why and how waste reduction was carried o-ut. Often it is not clear what waste has been reduced, how much it was reduced, by what method it was reduced, or what the costs and benefits were. Second, the number of cases reported in the literature is limited; the same examples appear over and over again. Third, comparisons between examples from one published source and another are difficult to make because there are no generally accepted definitions of wastes or reduction. Many examples deal with nonhazardous wastes, particularly in European documents; in other cases only a RCRA definition of hazardous waste is used, ignoring wastes in air and water. Similarly, waste reduction

Table 3-1 .—Waste Reduction Case Studies

	Waste reduction methods						
Sources	In-process recycling	Plant operations	Process technology and equipment	Process inputs	End products	Waste management methods	Totals
a	19	16	11	5	0	22	74
b	36	0	24	7	0	15	82
c	36	0	17	2	0	10	65
d	10	4	6	2	0	4	26
e	6	10	18	2	2	1	39
f	3	0	20	1	1	3	28
Totals.	110	30	96	19	3	56	314

SOURCES Office of Technology Assessment, compiled from:
a D Huisingh, et al., *Proven Profit from Pollution Prevention* (Washington, DC The Institute for Local Self-Reliance, 1985);
b. *Compendium on Low and Non-waste Technologies* (Geneva, Switzerland: United Nations Economic Commission for Europe, 1981-84), four volumes,
c. M. Overcash, Techniques *for Industrial Pollution Prevention* (Chelsea, MI: Lewis Publishers, Inc , 1988). Originally assembled and developed as *Les Techniques Propres* clans *l'Industrie Francaise* (Paris: The Ministre Du L'Environnement, 1982);
d. Department of Defense, Environmental Leadership Project, *Industrial Processes to Reduce Generation of Hazardous Waste at DOD Facilities,* Phase 2 Report: Evaluation of 18 Case Studies, prepared by CH2MHill (T E. Higgins), July 1985,
e. D Sarokin, et al., *Cutting Chemical Wastes (New* York: INFORM, 1985), and
f Federal Minister for Research and Technology (DFVLR), *Environmental Protect/on Technologies* (Cologne, West Germany DFVLR, December 1984). (Note that this last volume documents ongoing research rather than industrial application of technologies.)

definitions often include what is actually waste management. Examples of waste reduction in the literature may also include simple volume reduction (e. g., dewatering of a sludge) with no reduction of hazardous content,

In order to gain some insight into the literature, OTA analyzed six references which offered the most detailed and useful accounts of hazardous waste reduction. Table 3-1 shows the distribution of case studies in these six documents across the five different waste reduction approaches available to industry, Table 1-2 in chapter 1 shows the distribution of these same cases across Standard Industrial Category (SIC).[7] Of the 314 examples included in the six sources which dealt with a broad category of hazardous waste,[8] 110 of them described in-process recycling measures, 96 describe process and equipment changes, 30 describe operations changes and 19 describe input substitutions. Only 3 of the 314 cases were end-product reformulations, which is consistent with the unpopularity of this approach among industries surveyed by OTA.[9]

The distribution of approaches in the literature is similar to the ranking of approaches by companies surveyed by OTA. In-process recycling and technology /equipment changes are by far the most common method of reducing wastes, followed by plant operations or housekeeping changes. Input substitutions are rare; end-product reformulations are by far the least common method of reducing waste. As discussed above, the recycling and operations changes have an add-on character which makes them relatively easy to implement with little risk, Process and equipment changes are usually more difficult and risky to implement, but the potential payoff for such changes in terms of increased efficiency and reduced costs can be very large, The frequency with which such changes are documented in the literature indicates that major front-end waste reduction actions are both possible and profitable for a very wide range of industries,

The distribution of cases across SICs illustrates the wide range of industries that have become involved in waste reduction. However, the distribution should **not** be taken as any conclusive demonstration of waste reduction activity or lack thereof in any particular industry. Three of the the six compendia focus on only a few or even just one (1 NFORM) SIC category and therefore make no attempt to be representative.

[8]Some examples in the literature deal with waste heat and with nonhazardous wastes, for example from food processing. These were not included in OTA's tally.

[9]It is worth noting that even these three are not particularly good examples of waste reduction by end product reformulation. The two INFORM examples both involve eliminating filtration of a hazardous particulate from an adhesive so that it is passed on in the product—a change of questionable overall environmental benefit. The other example in the German compendium—an investigation into possible substitution of aluminum for cadmium in electroplating—is a piece of R&D done in a university research institute, not an example of successful waste reduction in industry.

Generic Waste Reduction Opportunities

Another way to illustrate waste reduction opportunities is by examining those that apply to common hazardous wastes or industrial operations. While it is correct that there are important site-specific constraints to waste reduction, many successful practices, which generally have paid for themselves within a period of month's to a few years, can be adopted by a broad range of companies and industries, Discussions of several of these practices follow,

Replacement of Organic Solvents

There are a number of successful examples of companies that have cut their costs and hazardous waste problems by changing from materials that contain large amounts of organic solvent,[10] such as inks, to ones based with water. There are also a number of examples of switches from pure organic solvents to water-based cleaning agents. This approach competes in popularity with in-process recycling of organic solvents, which is also widely applicable and on the rise, but the substitution approach is a better example of waste reduction.

Material substitution can eliminate, not just reduce, a particular waste stream and can also eliminate other problems, such as contamination from leaking underground storage tanks and worker exposure to the original solvent. However, problems with product quality may result; for example, a great deal of development was necessary before water-based paints achieved levels of color quality and durability similar to the solvent-based paints they replaced, By now there has been a record of so many successes in this type of substitution that a broad shift on the part of suppliers from organic solvents to water-based products for industry is likely, although organic solvents will continue to be considered essential or preferable in certain applications. This shift will especially benefit smaller firms that can buy the new products and cut their waste generation, There appear to be many waste reduction opportunities here, although in some industrial processes development work will be necessary, including major or minor changes in plant equipment.

[10]Organic solvents include methanol, hexane, toluene, methylene chloride, Freons, xylene, chloroform, isopropanol, acetonitrile, trichloroethylene, and many other compounds.

Organic solvents can also be replaced by materials other than water to reduce waste. For example, Merck, Sharp & Dohme has been successful in replacing some organic solvents with inexpensive inorganic acids and bases in pharmaceuticals manufacture. They report that the substitute process has eliminated 300,000 gallons of methanol and 300,000 gallons of hexane a year in the manufacture of one product. This and other manufacturing changes reduced the company's generation of chemical wastes by 5(J percent over 4 years. Recycling of 2.6 million pounds a year of methylene chloride meant a per pound savings of 24 cents for raw material costs and 35 cents for incineration.

In-Process Solvent Recovery

Solvent recovery falls within the definition of waste reduction in this report as long as the recovery equipment is used in conjunction with process equipment or within the waste generating activity area. In-process solvent recovery is widely used as an alternative to replacement of organic solvents to reduce waste generation. It is attractive because, like end-of-pipe pollution control measures, it requires little change in existing processes. The widespread commercial availability of solvent recovery equipment is another attractive feature. Availability of equipment suitable for very small operations, particularly batch operations, may make in-process recovery of solvents financially preferable to raw materials substitution for such firms, but for most companies the relative economic advantages of in-process recovery are less clear.

Commercially available solvent recovery equipment for in-plant use is summarized in table 3-2. The functioning of each of these pieces of equipment is based on one or more of the following methods:

- *Carbon adsorption* of solvent, subsequent removal of the solvent by steam, and separation of the solvent for reuse in the operation. This process works best with sol-

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Table 3-2.—Some Commercial Sources of Solvent Recovery Equipment[a]

Carbon adsorption:

AMCEC Corp. (Oak Brook, /L): Custom designed and packaged systems. A new process reduces resorption stream requirements from the conventional 3 or 4 lb steam/lb of solvent to 2 lb steam/lb of solvent recovered, or less.

Dedert Corp. *(Olympia Fields, /L):* Equipment and systems feature new technology to reduce energy consumption to less than 1 lb of steam/lb of solvent recovered for large-scale operations. Investment recovered quickly, often in less than 24 months.

Hoyt Manufacturing Corp. (Westport, MA): Can recover 85 to 95 percent of solvent with payback in less than 1 year.

Met-Pro Corp. (Systems Division, Harleysville, PA): Either granular or fiber carbon used.

Ray So/v, Inc. (Piscataway, NJ): Regeneration of carbon achieved by purging the adsorber with an inert gas in new system. This can reduce cost by 50 percent and energy requirements by 35 percent over conventional systems. Steam resorption system offers recovery efficiencies of 99 percent.

Vara International, Inc. (Vero Beach, FL): Uses pelletized carbon bed and automatically controlled systems.

Distillation/condensation:

Edwards Engineering Corp. (Pompton Plains, NJ): System based on direct condensation by refrigeration. Vapors are passed over cold condensing surfaces where solvent vapors condense and are collected as a liquid and returned to product storage.

Finish Engineering Co. (Erie, PA): Feat ures one button operation and no operator requirement.

Hoyt Manufacturing Corp. (Westport, MA): Distillation system recovery efficiency of 98 percent; completely automatic, continuous process.

Recyclene Products, *Inc.* (South San Francisco, *CA):* Small volume (5 gal) distillation recovery system available.

Distillation/condensation (continued):

Pope Scientific, Inc. *(Menomonee, WI):* Uses a vacuum distillation process. Capacity of up to 200 gal/day.

Sauk Valley Equipment Co. (Rock Falls, /L): Can distill 15 gal/shift at a cost of 4 to 10 cents/gal.

Progressive *Recovery, Inc. (Columbia,* /L): Distills all common solvents up to a boiling point of 5000 F with vacuum assist at a cost of 5 to 8 cents/gal.

pbr Industries (West Baby/on, NY): Two portable batch sizes (5 and 14 gal) recycle 90 percent of solvent (acceptable feed includes paint thinners, aromatic hydrocarbons, chlorinated solvents) automatically in a few hours. No pressure valve; costs less than 5 cents/gal. Special additive allows sludge reclamation and production of low-cost rubberized undercoating or gravel guard.

Scrubbers, other methods, or operating principle not known:

Cailcote (Berea, OH): Scrubber uses a proprietary high boiling point organic liquid that is regenerated and recycled. Stripper column has a fractionation section and a condenser. Process is continuous.

Tri-mer Corp. (Owosso, M/): A wet scrubber system for various types of industrial sources which can be combined with other devices, such as a distillation/conden sation device, for solvent recovery.

Detrex Chemical Industries (South field, MI): Modular approach which can be used with most chlorinated and fluorinated solvents. Many systems have paybacks of less than 1 year.

Venus Products, Inc. (Kent, WA): Systems can recover95 percent of solvent and up to 4 barrels per sh ift with automatic barrel filling.

Union Carbide (Danbury, CT): Recovery efficiencies of up 99 percent in large systems which can pay for themselves in about 2 years.

[a]This table is for illustrative purposes. The appearance of a technology in this table should not be construed as a recommendation or endorsement by OTA

SOURCE: Off Ice of Technology Assessment, based on Information supplied by companies and P.M Cheremisinoff, *Pollution Engineering*, June 1986, pp. 26-33

vents that are immiscible with water and when only a single solvent is being recovered. Since the carbon must be regenerated, two or more units are required to keep the operation continuous. There can be problems and costs associated with hydrochloric acid formation from chlorinated solvents, carbon bed plugging by particulate, and buildup of certain volatile organics on the carbon,

- *Distillation and condensation* are used to separate and recover the solvent from other liquids. Removal efficiency can be very high with this process. It can be used for solvent mixtures as well as single solvent streams.
- *Dissolving the solvent* in another material (i.e., scrubbing) can be used. The solvent must then be recovered from the resulting solution, for example through distillation and condensation. Efficiency of removal is often not high with this method.

Mechanical Instead of Liquid Processes

Whenever liquids are used to transfer or remove material, it maybe possible to accomplish the job by a mechanical means. For example, metal beads can replace a caustic solution to remove dirt or oxide on metal parts. Some types of plating can be done mechanically rather than with traditional electroplating methods. Paint can be removed by bombardment with plastic or metal beads rather than by using solvents. Nonmechanical sources of energy can also replace liquid chemicals; for example, the Air Force has developed a high-intensity flashing light to strip paint from aircraft wings.

Preventing Vapor Losses

Often it is possible to prevent hazardous air emissions by the simplest of techniques while realizing large cost savings on raw materials. Since there are often no government regulations on control of toxic fugitive emissions, often little thought has been given to the subject, although it is easy to design equipment that will do the job. For example, Exxon Chemical Americas reduced emissions by 85 percent or more with floating roofs on open tanks of volatile materials, Other techniques include: installing condensers in or near operations to turn vapors into liquids, which are easily reused; increasing the height of vapor degreaser tanks to increase the distance between the vapor and the top of the tank; and using automatic tank covers that close between each decreasing operation. Another approach is to convert from batch to continuous process. For example, Monsanto changed polystyrene production some years ago from batch reactors to a closed-system continuous process. As a result, air emissions dropped from 5 percent of total production to less than 0.02 percent.

Reducing the Use of Process Water

Remarkably large volumes of hazardous aqueous waste result from the widespread use of water to transfer heat and materials, particularly in the cleaning of equipment in batch processes. For the most part, these wastes are extremely dilute solutions with very low concentrations of hazardous substances—so low that it is not practical to remove and reuse them. Either the aqueous waste is managed as a RCRA waste or it is put through a water treatment plant that typically either creates sludge for land disposal or releases hazardous air emissions. Historically, water has been so cheap and the costs of managing dilute aqueous wastes have been so low that it is has been used with little thought of the hazardous waste consequences. There are probably almost countless opportunities to cut down on waste created by the contamination of process water, but there are also obstacles. See box 3-F for an illustration of both the possibilities for and the limitations on reduction of wastewaters created in the manufacture of acrylonitrile.

When water is used strictly for the removal of heat, then heat pump or refrigeration systems based on circulation of coolants in a closed-loop can be used instead. The problem with using cooling water is that chemical agents are added to minimize bacterial growth and slime buildup on cooling coils; such agents may, for example, contain chromium, which eventually renders the water hazardous.

In many industrial operations water is used as a solvent, but organic solvents can be so much more potent that reductions in water use of two or three orders of magnitude maybe possible. The higher initial cost can be more than offset if the organic solvents are cleaned and recycled, Recycling can also facilitate removal and possible reuse of the dissolved materials. As the cost of managing hazardous wastewater increases, the use of organic solvents might increase.

Another major industrial use of water is as a medium for precipitation. The result is wastewater that may contain 1 to 15 percent dissolved hazardous inorganic salt. Precipitation for product recovery might be replaced by separation techniques such as membrane technology,

Large quantities of water are used for cleaning, and a good example of reduction is to replace high-volume streams of water for cleaning tanks, equipment, and products with systems that use much smaller amounts cyclically. Other approaches include pressurized water or drip tanks to collect chemicals rather than a water tank; counterflowing multiple rinse tanks; and squeegees to remove residues. Smaller pipes or flow restrictors will inhibit workers from wasting water. Yet another approach is to schedule batch processing to maximize back-

Box 3-F.-Possibilities for Reduction of Hazardous Water From Manufacture of Acrylonitrile

In 1985 acrylonitrile ranked 38th in the list of the top 50 chemicals made in the United States, ranked 20th out of the 26 organics on the list, and had the highest growth rate of the organics from 1975 to 1985 with an annual average rate of 6.8 percent. Production in 1985 was 2.35 billion pounds (1.1 million metric tons).[1] For each metric ton of acrylonitrile product manufactured, 2.3 metric tons of process water and 400 metric tons of cooling water are used.[2]

Process Water.-Water is used primarily as a quench neutralizer to cool the reactor effluent and neutralize any unreacted ammonia. Sulfuric acid is added to process water, and the acid solution is added directly to the quench neutralizer tower to effect very rapid cooling. Effluent from the quench tower is aqueous waste, essentially an ammonium sulfate solution. Based on the production rate of acrylonitrile, an estimated 2.5 million metric tons of process wastewater is generated annually. This is roughly 1 percent of the national hazardous waste stream. The disposal cost of the wastewater is estimated at $30 to $60 per metric ton of product based on using deepwell injection for waste disposal; the product cost is estimated at $560 per metric ton.

Possibilities for Waste Reduction.—A process technology change is difficult because the process water serves two purposes: it cools the reactor effluent and serves as the medium for neutralizing the excess ammonia. Indirect cooling via a heat exchanger would probably not be rapid enough to replace the direct quench, and use of a heat exchanger surface might lead to the formation of tars or other undesirable side reactions. Moreover, indirect cooling would not accomplish neutralization of the excess ammonia. To change the acrylonitrile manufacturing process to eliminate or reduce process wastewater would constitute a major change. A large research effort might be required with a pilot and demonstration project and might take 5 to 10 years at considerable cost. Since the cost of the process wastewater is only 5 to 10 percent of the total production costs, such an effort is not attractive. If wastewater management costs were significantly higher, say twice or three times as much ($60 to $180 per ton of product), perhaps because of shifting from injection wells to treatment, then the effort might be justified.

Cooling **Water.—**For every gallon of cooling tower water circulated, a small fraction called blowdown is discarded to remove the buildup of slime and solids which accumulate during recirculation. This blowdown contains toxic chemicals used as bactericide and fungicides and is a hazardous waste. A typical blowdown ratio is about 0.5 percent of the circulation rate. For each 400 metric tons of cooling water used per ton of product, 2 metric tons of blowdown wastewater is generated. Thus, about 2.2 million metric tons of this wastewater is generated annually. Disposal cost of the wastewater ranges from about *$26* to about $52 per metric ton of product, or 5 to *10* percent of product cost.

Possibilities for Waste Reduction.—Here the water serves only one function, cooling. An alternative could be the use of a heat pump cycle to reject heat to the environment from a closed-loop coolant refrigeration system. After the coolant was used to cool the process, it would be compressed to a higher temperature and pressure and then passed through a radiator that would reject the heat to the environment. The operating costs for cooling would be from $17 to $60 per metric ton of product.[3] The costs for managing the traditional coooling wastewater, if injection well costs are from $0.05 to $0.10 per gallon, are $26 to $52 per hour per ton of product. (This cost could increase if a waste management shift occurred from deepwell injection to waste treatment.) There is a clear potential for saving perhaps $2o per ton of product if closed-loop, efficient refrigeration were used instead of conventional watercooling. For a 100,000 ton per year plant this means a saving of about $2 million annually. Assuming that the capital costs of the refrigeration system might be at most about 10 percent of the original capital costs of the pIant, $5o million, then payback would occur in a few years.

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[1]*Chemical & Engineering News,* Apr. 21, 1$S6.

[2]*Hydrocarbon Processing,* May 1977, p. 171. Data based on Montedison-UOP process, which differs from the more widely used SOHIO process primarily because of a different catalyst. However, similar water use and wastewater generation can be assumed for both.

[3]The operating costs can be estimated making the following assumptions: 1) cooling water temperature rise of 12° F, z) coefficient of performance ranges from 2 to 7, and 3) energy costs are $0.04 per kilowatt-hour.

to-back production of' products, thereby minimizing washdowns.

In many of these approaches a smaller volume of water with more highly concentrated contaminants is generated. This water sometimes can be directly recycled into production systems or can be economically treated to recover valuable components, such as metals and oils, for recycling back into the process, For example, Borden Chemical Co. stopped filling reactor vessels with water to clean them and instead used 5 percent of the previous volume for the initial rinse, allowing a concentrated solution of phenol resins to be recycled back into production.

There is an array of technologies under development to separate and remove valuable substances from wastewater. These include: membrane technologies such as electrodialysis, reverse osmosis, ultrafiltration, liquid membranes; adsorption technologies that use a variety of materials such as activated carbon; and bubble and foam separation. One or more of these techniques might be applicable to a particular waste stream.

Another important aspect of recovering contaminants is that many of these technologies allow the use of closed-loop systems in which process water is recycled rather than being passed through the system a single time. In some locations, such approaches are attractive simply because they drastically cut water consumption. Moreover, this approach can eliminate the generation of large amounts of sludge in water treatment plants.

Many different types of industries, not merely the chemical industry, could explore opportunities to reduce wastewater volumes. For example, a recent development concerns spent metalworking fluids. After 4 years of laboratory research and field trials, Eaton Corp. installed a patented system in a number of locations to totally recycle its metalworking fluids in-plant. All this spent metalworking fluid, which contains 95 percent water, is reused and it is claimed that the system can be used anywhere, regardless of operating conditions, Presumably the system will be marketed to other companies.

The Limits of Examples

Hundreds of case studies and examples of waste reduction in the United States and abroad document the technical feasibility and economic benefits of a variety of approaches in a wide span of industries. Yet it is difficult to know whether individual examples and case studies represent the rule or the exceptions in current industrial practice. It is a situation in which those who have achieved success are encouraged to speak of it publicly, while those that have not remain silent.

In many of these published examples no data or very limited data are given on the total waste context in which one or more specific wastes were reduced, and if any data are given for actual waste reduction they are hardly ever given in terms of production output or environmental risk reduction. It is not always clear whether some of the waste is not simply being transferred from one environmental medium to another or whether a new hazardous waste is being generated in place of the old one,

An unfortunate limitation of waste reduction examples is that the generic opportunities are often not recognized. A reader notes the particular industry being discussed and if it is not his industry, he needs imagination to see that the waste reduction method might still be applicable. If the examples were redrafted to put them into functional or general terms it might be easier to transfer waste reduction measures across industries.

Most importantly, the literature contains next to nothing about *failed* waste reduction efforts, nor does it provide detail on how problems were solved in cases that were ultimately successful, Moreover, human and organizational factors that went into a waste reduction decision are rarely discussed, even though these can be as instructive as technical and economic information. Rarely is there attention paid to which internal or external factors, such as corporate policy or government regulations, had a major role in the success of the effort.

Overall, the waste reduction literature and conversations with people in industry point to two conclusions: first, that waste reduction is

widespread, diverse, substantial, and economically justified; and second, that more can be done. Traditionally, waste reduction has been considered only as a consequence or byproduct of work to improve yields and efficiency. As was the case with energy conservation, once waste reduction becomes a major industrial goal and a criterion of industrial efficiency in its own right, opportunities not previously considered viable will be acted on and new opportunities for waste reduction will be identified.

INDUSTRY DECISIONMAKING ABOUT WASTE REDUCTION

There is no standard method by which companies make decisions about waste reduction. For the most part, waste reduction has been carried out on an ad hoc basis. A troublesome or costly waste is identified and specific action is undertaken to reduce or eliminate its generation. Wastes are often reduced by process improvements in which waste reduction is only a minor consideration. However, as waste reduction begins to appear and rise on the agendas of CEOS as an issue in its own right, systematic audits are beginning to be developed to guide comprehensive waste reduction.

Conducting a Waste Reduction Audit

Waste reduction audits are distinct from environmental audits. Environmental audits are compliance audits—they are internal reviews of a company's operations aimed at meeting environmental requirements such as RCRA and the Clean Water and Clean Air Acts.[11] Waste reduction audits are systematic, periodic internal reviews of a company's processes and operations designed to identify and provide information about opportunities to reduce wastes. They provide a useful tool for companies undertaking systematic, comprehensive waste reduction.

Such a comprehensive examination of operations requires a broad scope of expertise, probably beyond that of any one person in a company. Review of all processes and operations for all five types of waste reduction opportunities requires familiarity, not only with environmental requirements and waste management activities, but also with process engineering, operations, and product design. A waste reduction audit is best carried out by a group of people, each one with expertise in a different one of these areas; an environmental engineer alone cannot do it.

Involving people from different parts of the company in the waste reduction audit has the added advantage of increasing consciousness of the need for waste reduction. It can stimulate employees to think about methods of reducing waste and help shift thinking away from the pollution control focus.[12]

The comprehensiveness of waste reduction audits and the types of actions that will emerge from them also depend heavily on the way terms are defined, Depending on how waste reduction is defined, the audit may or may not review waste in all environmental media, focus on reduction of waste generation at the source, and measure reduction on a product output basis.[13]

[11]For more information on environmental auditing see, U.S. Congress, General Accounting Office, *HAZARDOUS WASTE: Federal Civil Agencies Slow to Comply with Regulatory Requirements* (Gaithersburg, MD: May 1986), pp. 51-59. Also, U.S. Environmental Protection Agency, "Environmental Auditing Policy Statement, " 50 Federal Register, Nov. 8, 1985; K. Geiser, "Critical Elements of a Waste Reduction Plan, " paper presented at Government Institutes Conference on Hazardous and Solid Waste Minimization, May 8-9, 1986, esp. p. IV-10; and M.A. Smith, *A Handbook of Environmental Auditing Practices and Perspectives in North Carolina* (Chapel Hill, NC: Institute for Environmental Studies, 1985).

[12]See D. Huisingh, *et al.*, *Proven Profits from Pollution prevention* (Washington, DC: The Institute for Local Self-Reliance, July 1985), p. 15. A hierarchy for pollution prevention strategies is also presented here which places waste audits at the top.

[13]Very often, waste reduction audits are based on the EPA term *waste* minimization which gives equal status to reduction and recycling and so will identify such actions as equally valid options, regardless of which poses a greater environmental risk. Often, too, waste reduction audits concentrate on RCRA wastes or wastes destined for land disposal and review other emissions only incidentally, These two problems are exemplified by the

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Because waste reduction audits are new, they take a variety of names and forms. Among companies that have started auditing, each tailors its review to its own peculiar needs, Consulting firms that have begun marketing waste reduction auditing each packages its procedure a little bit differently.[14] However, OTA was able to identify a series of basic analytic steps in most systematic audits. The order of the steps may vary and two or more may be combined, but each of these points must be considered in any comprehensive and systematic waste reduction analysis,

Step 1: Identification of Hazardous Substances of Concern in Wastes or Emissions

This analysis may be done at radically different levels of detail.

Level I:—Companies may make only a very gross analysis of the contents of their wastes. This occurs commonly in some small businesses which may not have the people, money, or knowledge to conduct detailed analyses and collect detailed data. In practice, this stage of review may be no more than the realization that a company is wasting a great deal of a chemical. The focus in such cases is on quantities of particular wastes.

Level 11:—Companies may systematically conduct chemical analyses of all their wastes over a given time (especially important in batch processes where wastes vary) to get more precise data about both chemical composition and amounts of waste. The difficulty here lies in identifying and measuring *all* wastes, including all fugitive emissions, leaks, and spills.

Level III:—Companies can do mass balances on hazardous substances, By subtracting the amount of a hazardous substance going out in the product from the amount purchased as raw material (and taking into account reaction processes and products), a company should be able to calculate how much of the substance is generated as waste. However, accounting for all of the waste streams, emissions, leaks, and spills in the operations usually requires a great deal of time and many resources, and such procedures are generally considered only when an action is required on a particular substance of concern. Even for a small manufacturing operation, compiling and updating mass balance information on even one hazardous substance in the plant can be a big job. Moreover, no information specific to a process may be obtained from a mass balance done on a plant basis, Chapter 4 discusses in more detail practical difficulties with conducting mass balance calculations of sufficient sensitivity to be useful for waste reduction,

Step 2: Identification of the Source(s) of the Hazardous Substance(s) of Concern

Identifying the process source of the waste for a specific product is essential. Without knowing which processes are generating which wastes a company cannot know what actions are required to reduce those wastes. Uncovering this information may take time and resources and may be made more difficult by accounting methods a company uses. If waste management costs, for example, are routinely charged to some general environmental operation, then the connection between waste and production process and product may not be apparent.

Step 3: Setting Priorities for Waste Reduction Actions

Companies must decide which types of waste to target for reduction and at which points in which processes, In practice, this may be an independent, external decision directed for example, by government regulations, rather than a free choice. In the absence of external determinants, recognition that a waste is environmentally hazardous may also play an important role in waste reduction decisions. To assist

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waste reduction audit procedure found in C.H. Fromm and M.S. Callahan, "Waste Reduction Audit Procedure-A Methodology for Identification, Assessment and Screening of Waste Minimization Options," paper presented at a Hazardous Materials Control Research Institute conference, Atlanta, GA, Mar. 4-6, 1986.]

[14] See, for example, K. B. Pojasek, Chas. T. Main, Inc., "Conducting a Waste Minimization Audit. *Hazardous and Solid Waste Minimization* (Washington, DC: Government Institutes, Inc., May 1986). Also, M. R. Overcash, *Techniques for Industrial Pollution Prevention* (Chelsea, MI: Lewis Publishers, Inc., 1986), p. 15.

proper economic evaluation of the costs of waste generation and management and the savings from waste reduction, waste generation should be measured on a production output basis. Not putting costs and savings on a product basis could lead to poor business decisions, For example, what appears to be a relatively small waste management cost for a waste may be otherwise when assessed in relation to a small profit margin for a product and vice-versa.

Step 4: **Analysis and Selection of Technically and Economically Feasible Waste Reduction Techniques**

After a waste is targeted for reduction, the problem of choosing one or more feasible waste reduction techniques remains, Different techniques will offer different levels of effectiveness at a different cost and at differing levels of risk, If there is no pressing reason to reduce one waste rather than another, companies may decide to take action first on the wastes that are the easiest and least costly to reduce and postpone the more difficult waste reduction problems for later, A great deal depends on the information base obtained, the technical resources, and the economic circumstances of the particular firm.

Step 5: **Economic Comparison of Waste Reduction Alternatives to Waste Management Options**

Once attractive waste reduction alternatives have been identified, they still must be proven preferable to pollution control. In most companies, waste management is the known, safe option that provides a clear result for an investment and creates minimal disruption and risk to production operations. For most firms, waste reduction is a newer approach that has the potential for widespread effects including interference in process operations and possible alterations of product quality. Waste reduction may, therefore, be perceived as economically risky by industry decisionmakers.

Step 6: **Evaluation of the Progress and Success of Waste Reduction Measures**

This step is critical to the disposition of the company to take further action to reduce waste. Companies must document both the benefits and costs of waste reduction, if they are to make informed decisions about whether to take further waste reduction measures, Obtaining data regularly on waste generation on a production output basis is the best way to evaluate the technical and economic success or failure of waste reduction,

Constraints and Incentives Affecting Waste Reduction Decisions

Proven technologies and the opportunities industries have for waste reduction do not themselves guarantee these technologies will be used. Factors that affect the ability and willingness of companies to implement waste reduction measures include:

1. the nature of the company's industrial processes,
2. the size and structure of the company,
3. technology and information available to the company,
4. attitudes and opinions that affect company operations,
5. the economics of waste reduction, and
6. government regulations.

Whether these factors serve as constraints or incentives for waste reduction will vary even among different plants within the same company.

Because the Federal Government's current waste minimization program is *voluntary (see* ch. 5), the degree to which these factors motivate or deter industry from waste reduction has determined the amount of waste reduction accomplished to date, Understanding these constraints and incentives is therefore essential for formulating Federal policy. They will affect regulatory options, for example, because the economics of waste reduction in different industries may influence the decisions government makes about mandating levels of waste reduction, However, these elements of industrial decisionmaking are particularly important in assessing nonregulatory Federal policy options. Nonregulatory programs rely on persuasion rather than on coercion to influence decisions.

The following analysis attempts to shed light on: 1) the relative importance of these factors in different situations, 2) the relationship among these factors, and 3) opportunities that may exist for government to manipulate these incentives and constraints to influence industrial decisions about hazardous waste reduction. The analysis must be prefaced with two points about industry decisionmaking.

First, decisionmaking procedures in industry vary greatly; generalizations of the type presented here will inevitably invite exceptions. This discussion deals with only a few of the most important and influential elements in industry decisions. A wide variety of other considerations may also shape the decisions in a particular company.

Second, change represents risk. If business is going smoothly, the inclination is not to make changes unless there is some clear reason to do so. However, if an industry is in trouble, there may also be resistance to innovation. Resources are likely to be concentrated on the obvious threats to survival rather than on making changes for waste reduction, Thus, in general, *the burden is on the proponents of waste reduction to justify change*. If the case for waste reduction is not made clear to the industrial decisionmaker, waste reduction will not happen.

Nature of Industrial Process

The most important factor in the ability of any company to reduce its generation of hazardous waste is the character of its industrial processes, These determine the waste reduction opportunities that will be appropriate and applicable (see table 3-3). There are more opportunities for waste reduction in some industries and some processes than in others. Several features of industrial processes can be identified which affect the probability that waste reduction opportunities will be available.

First, the frequency with which operations and/or processes must be redesigned for routine business reasons is important. For example, some manufacturers of consumer products are under pressure to put out new product designs frequently. Most product changes require some type of operations change; frequent prod-

Table 3=3.—Potential for Waste Reduction Opportunities Across Different Industry Types

Company/industrial characteristic	Example industries	Operations changes	In-process Recycling	Process changes	Input substitution	End product changes
Mature process technology, high volume product	Rubber Petroleum Commodity chemicals Paper products Lumber	+	+			
Very stringent product specifications or high product quality demands for high cost/high profit products	Pharmaceuticals Weapons Robotics Specialty chemicals	+	–		–	
Frequently changing, high-tech products for industrial use	Electronic components Medical equipment	+	+	+	+	
Job shop processing of many different industrial products	Electroplating Printing }	+	+	+	+	
	Foundries Machine shops }	+	+	–	+	
Changing production technology for commodity goods	Steel making Nonferrous metals Textiles	+	+	+	–	–
Large-scale manufacture of consumer goods	Automobiles Appliances Consumer electronics Paints	+	+	+	+	+

SOURCE Off Ice of Technology Assessment, 1986 uct reformulation makes a company conscious of its daily operations and of opportunities to reduce waste without endangering the new product design.

However, the relationship between product reformulation and process change (which tends to be harder to implement than operations changes) is more complex. Product reformulations may not require process changes. For example, changing the circuit design for a new model of a company's personal computer does not change the requirements for plating and etching, which produce most of the industry's waste. On the other hand, some product changes do involve a different process, such as those that require completely different materials, A manufacturer of home appliances, for example, may take advantage of the introduction of a new model of blender to switch from chromium plating on the machine casing to a nickel plating or to a plastic unit. Some of these alterations may eliminate one hazardous waste, but produce a new one.

It is even possible that product redesign may force changes that create more waste or more hazardous waste than previously. The semiconductor industry is starting to use gallium arsenide (GaAs) semiconductors in some applications. GaAs semiconductors are faster and use less power than their silicon-based counterparts. The manufacturing processes are similar to those for silicon products, but the introduction of arsenic, a known human carcinogen, increases the hazard of the wastes and increases the hazards in the workplace.[15]

Despite opportunities offered for waste reduction, it is unrealistic to expect businesses to redesign products or processes except under pressure from the marketplace or when impelled to do so in order to comply with government regulations. Redesign of a product or a process is expensive and risky, When the market for a product expands, requiring additional plant facilities, process change may become more feasible. For example, this has happened at times in the specialty chemicals industry where some firms have set up new production lines for chemicals in high demand.

In some mature industries such as petroleum refining and commodity chemicals, where there is little call for product or process change, opportunities for waste reduction may be limited. In other mature industries, intense competition from overseas has stimulated the use of new but proven processes that permit the manufacturer to make a better quality and less expensive product. The textile and steel industries are cases in point. However, even in mature industries with little potential for process and product change, opportunities for operational changes and in-process recycling may exist and may offer broad benefits beyond waste reduction. They may not, however, be pursued because of limited resources and other pressing needs that have higher priority.

Another industry characteristic affecting waste reduction opportunities has to do with the product quality. Cases in which the market demands very high quality, as in pharmaceuticals, may provide fewer opportunities for input substitution or in-process recycling, Operations in these plants may also produce large quantities of substandard product waste because of the quality demands on the product. High-quality products generally carry both high costs and profits, making such industries less sensitive to waste *management* costs and reducing economic incentives for waste reduction.

It may also be difficult to find less-hazardous or nonhazardous raw materials for the manufacture of some high-performance machinery. Water-based paints are now being used in many applications since they eliminate the need for solvents which then become hazardous wastes. While these paints may be perfectly adequate for many household appliances, they may not be adequate for the stresses placed on high-performance machinery, such as jet aircraft.

Product quality is by no means a consideration only for specialized industries (see box 3-E). One major automobile manufacturer recently considered installing a huge countercurrent

[15]Susan *Sherry,* et al., *High Tech and Toxics: A Guide for Local Communities* (Washington, DC: Conference on State and Local Alternative Policies, October 1985), pp. 109-112.

rinsing operation in a new plant to save water and cut down on aqueous wastes from painting, Prior to painting, auto bodies are dipped in successive baths which clean the metal of dirt and oil, apply a zinc phosphate coating to increase paint adhesion, and apply a chromium anti-corrosion coating, Between baths the car body is rinsed with a water spray. This is usual practice in both this auto firm and among its competitors. When designing a new plant in an area of scarce water, it was proposed to conserve water with a counterflowing rinse. The idea was rejected in part because the company was unwilling to risk problems such as paint peeling and nonadhesion which might occur if the new rinsing procedures were less thorough than previous procedures. The company decided that even if the procedure promised to perform as well as the old method after a shakedown period they were unwilling to risk any interval of even slightly lower product quality. They feared jeopardizing their standing in a market where foreign competition has made quality a major issue. This example is also an illustration of the problem of making changes in a production line that must perform without interruptions.

Another aspect of product quality which may influence the ability of companies to modify processes is the degree to which manufacturing processes are dictated by product specifications. The Department of Defense (DOD) often specifies manufacturing processes in its contracts as a means of maintaining quality in its high-performance equipment. These specifications are usually based on design work done by the DOD contractor and on extensive field testing of products. Opportunities exist at the design stage for the manufacturer to incorporate less waste-intensive features into the process, However, the procedure for modifying DOD specifications is so slow that even if a contractor discovers less waste-intensive methods of manufacturing products of equal quality, he almost certainly will not be able to implement them within the time of his contract. Hindrances to the use of new waste reduction techniques also arise from the fact that many types of DOD equipment stay in production for 20 years or more.

Rigid DOD specifications also raise the question of what level of quality is really necessary. For example, DOD requires cadmium plating on many of its aircraft parts since it is less subject to corrosion than the more common nickel plating. However, cadmium is a particularly hazardous material and from an environmental perspective it would be beneficial to substitute nickel or some other material wherever possible. A review of required performance levels *at the front end of the product-design process* might eliminate the need for some of this cadmium. A review of all DOD specifications might eliminate the need for other hazardous materials.

DOD has recognized the barriers its specifications place on waste reduction efforts and is currently reviewing this problem as part of its waste minimization efforts (see ch. 5).

Similarly, the Food and Drug Administration places product formulation and process requirements on pharmaceuticals manufacturing. Government regulators are slow to grant permission for process modifications or input substitutions in this area.

Size of Firm/Corporate Structure

The size of a company and the way it is structured strongly influence the way it makes all decisions, including those about waste reduction, Small businesses tend to have fewer people involved in decisions about waste, and those people are more likely to be familiar with the processes and wastes in question. In an electroplating shop employing 60 people, for example, a plant manager and company president or owner are likely to make all the decisions about wastes themselves and to implement change without extensive memo writing, instruction manuals, or clearance from superiors.

In large businesses, on the other hand, people intimately familiar with the processes are often far removed from those with the power to make decisions about plant operations and process change, Communication between groups in large corporations can be an important barrier to implementation of waste reduction measures. Decisions and plans made at the corporate level to reduce waste may not be well communicated or well implemented at the plant level, particularly if these plans have been formulated with little coordination at the plant level. Another problem in large companies is that environmental engineers are most often assigned to the end of the process where they *manage* the wastes that are produced, and it is usually they who are given responsibility for waste reduction despite the fact that they have little contact with the design engineers and researchers who lay out the process at the front end. Similarly, plant process and operations people may have only limited contact with those responsible for major process and product changes.

The number of people involved in decision-making differs from one company to another. Small firms are likely to make informal decisions, relying on their own professional judgment and experience since they are unlikely to have the resources to undertake extensive quantitative assessments of alternatives. In large corporations decisions are made or approved by many people of diverse knowledge and background who are often only peripherally familiar with the technology involved. The need to convince nontechnical managers that waste reduction measures are desirable and can be financially justified requires quantifiable (i.e., economic) analysis. Large businesses are therefore likely to make waste reduction or any other environmental decisions slowly, to conduct assessments of waste reduction options, and to formulate plans, programs, and goals before implementing them, There are no data to prove that either of these decisionmaking styles is intrinsically more or less favorable to waste reduction,

Among larger companies structure also affects how decisions are made. Some companies are very decentralized, Each plant manager can make major process and operations decisions without corporate approval, In other companies, corporate headquarters govern many aspects of the day-to-day running of individual plants. Again, neither of these situations is necessarily more or less favorable to waste reduction, but the diversity does mean that different companies may be constrained in different ways. A decentralized company may have a strong corporate policy commitment to waste reduction, but if plant managers feel there are insufficient incentives, reduction is unlikely to occur or will be implemented only slowly. Similarly, if a plant manager in a centralized company is more interested in reduction measures than are corporate managers and perhaps other plant managers, reduction measures are unlikely to occur.

Technology and Information Available

Industry type and company size affect to what extent new technology and information will be available to a company. In some industries a great deal more information about waste reduction techniques and technologies has been developed than in others. Company size, and to some extent industry / process type as well, affect whether a company can develop information and technology in-house when it is not available elsewhere. As mentioned earlier, significant change in company operations for waste reduction is risky. Firms, therefore, look for techniques and technologies that have been successfully demonstrated and used elsewhere, unless the alteration under consideration can easily be tested or implemented. There are more proven measures for some types of processes than for others. A small but growing number of vendors and consultants offer equipment and services for waste reduction, Increasingly, sellers of waste reduction services are or were waste generators who have successfully developed procedures in-house and are profitably selling their expertise and equipment to others.

Development and marketing of transferable technology is likely to occur among small firms which run generic operations and which are regionally based and therefore not in direct competition. For example, printing firms and electroplating job shops that do not compete but serve discrete local communities are industries likely to market waste reduction techniques. Proprietary concerns frequently inhibit this kind of technology transfer, particularly when firms compete directly for the same customers. This is often the case in industries where there are only a few large producers and markets are national. Commodity chemicals, for example, has always been a very competitive industry. However, larger producers are likely to have their own R&D facilities to develop technologies in-house (see discussion below),

The dissemination of waste reduction technologies and techniques is more complex than transferring established pollution control technologies to comply with the Clean Water or Clean Air Act. End-of-pipe control usually requires a fairly limited set of solutions, often involving installation of an off-the-shelf piece of equipment. Waste reduction, on the other hand, may involve a diverse set of techniques applied at the front end to processes or equipment or within operations. A relatively small number of reduction techniques are generic enough to be transferred with simple off-the-shelf equipment or standard prescriptions. When available, this equipment may only have the capability of reducing a limited number of wastes at a plant and these may not be the wastes that occur in the highest volume or are the most hazardous.

There is, however, a large body of literature about waste reduction in a wide variety of industrial processes, but technical assistance within a plant maybe necessary for implementation. Only the least complex reduction ideas (e.g., housekeeping changes) are likely to be directly transferable to other plants, However, most of the process change literature is inadequately detailed and very few industrial operations are so generic as to allow direct implementation of waste reduction measures from published materials without significant in-house research and experimentation. However, the sharing of information remains important, and just hearing about another firm's successful action at a conference or through a publication may be helpful.

Most waste reduction measures documented by OTA have been the result of some in-house research and development, tailoring techniques to the needs of a particular operation. However, only large firms are likely to have the money and, more importantly, the technical people to embark on large R&D programs to solve their waste reduction challenges. Smaller firms may have limited R&D facilities, particularly in industries such as specialty chemicals where some amount of R&D goes on as part of business.

One common obstacle to waste reduction in many smaller companies is that they purchase much of their technology and raw materials from larger companies. Small printing companies cannot begin using water-based inks until a major supplier brings them out on the market, Manufacturers of machinery are dependent on their suppliers to develop a quality lead-free paint before they can eliminate their lead wastes,

Small firms trying to avoid or reduce hazardous waste generation need information about the chemical contents of raw materials from suppliers. Instead of listing the chemicals in the raw materials, labels may simply state that: "contents are proprietary. " Unless they know what is going into their processes, users cannot screen inputs for unnecessary hazardous constituents that may later appear in their wastes (or products). For example, a small firm making caulking compounds and sealants that does not generate hazardous waste ordered a raw material from a supplier. The firm specified that it did not want the material if it contained formaldehyde because formaldehyde would render the firm's waste hazardous, When the material arrived the label contained no information about constituents, but testing proved that the material did, indeed, contain formaldehyde. Another firm might not have had the resources or the foresight to test.

The labeling problem has been somewhat alleviated by the institution of OSHA worker right-to-know measures which require that all vendors supply buyers with Materials Safety Data Sheets (MSDS) detailing all hazardous constituents, OTA has heard some complaints about lack of specificity on some MSDS, but this requirement now gives buyers information (or allows them to demand information) vital for waste reduction and waste management as well as for worker safety.

Attitudes and Opinions Affecting the Company

Although there is no way to predict attitudes of top-level decisionmakers in a company, it is unquestionable that personalities and personal attitudes do have an important effect on implementation of waste reduction, This is particularly true in small companies where a company president or manager maybe personally interested in hazardous waste problems and become a leader in the field. Even among large corporations, it is clear that some companies are more or less well disposed toward expending resources on environmental protection or waste reduction, viewing these goals as essential to the health of the company. A few companies, notably 3M, have gone so far as to articulate and publicly support pollution prevention as an alternative to pollution control and in so doing have created a positive attitude throughout the company toward waste reduction.

Lack of awareness about and commitment to waste reduction may influence actions involving waste at all levels of company operations. Environmental engineers can be blinkered by their experience with waste management. Environmental protection has been equated with pollution *control* for so long that many environmental engineers may not think of waste reduction as a serious near-term, economically beneficial option for solving waste problems. Even if environmental staffs are interested in waste reduction, they frequently are devoting all their time and resources to keeping the company in compliance with pollution control regulations.

Worker training is essential to educate people who operate processes about practices which create less waste, These may include simple things such as not leaving faucets running and avoiding spillage. Some larger companies have already put together videotapes aimed at educating all levels of people in the company about the importance of reducing waste.

Opinion outside the company may also influence waste decisions made within the company. Public opinion is important at a local level–in the siting of plants dealing with hazardous materials—and at the national level, as public fear about hazardous wastes increases pressures for better waste management and waste reduction. People in industry often feel that these fears are overstated or unjustified and may feel frustrated in their attempts to ally public fears about hazardous materials. The information the public receives about industrial hazardous waste is usually focused on accidents and Superfund sites and is overwhelmingly negative, Positive information about advances in waste management or waste reduction rarely make front page news. In addition, many of the horror stories about hazardous wastes, particularly at Superfund sites, came about because of waste handling practices of the 1950s, not the 1980s. Thus, despite their desire to calm public fears, industry decisionmakers often feel that they have little to gain by compiling and presenting information about successful waste reduction and management programs for the public. On the other hand, some companies have used waste reduction as an opportunity to portray a more positive image of their company for the public, and more may do so. Finally, some firms are committed to the siting of new hazardous waste management facilities and waste reduction may be perceived as a threat to siting; much depends on the extent to which waste reduction is perceived as a near- or long-term opportunity.

Economics of Waste Reduction

Economics is the driving force for most business decisions, and waste reduction decisions are no exception. Assessment of financial costs and benefits can act as either an incentive for or a constraint on waste reduction depending on a company's or a plant's circumstances. If an operation's waste management costs are high and it finds that it can institute significant waste reduction measures with relatively low costs, thereby saving on waste management expenditures, the company will be inclined to reduce waste, If, on the other hand, waste management costs are low relative to total costs or if costs (e. g., cleanup liabilities) are not immediately born by that operation, a company may decide not to disrupt or put at risk its processes, operations, and products with waste reduction, even if some relatively easy, low-cost reduction measures are available. The outside analyst generally does not attempt to estimate the economic consequences of such disruptions and risks and for this reason the costs of waste reduction may be perceived in a more positive light than is warranted.

According to the respondents to OTA'S industry survey, the rising costs of waste management and associated liabilities for waste disposal are the primary considerations of companies that plan to implement waste reduction. These considerations are more critical to industries in which waste management costs are a high proportion of operating costs or of profits, Examples include electroplating, steelmaking and commodity chemicals, and companies that have already experienced substantial penalties for past waste management practices. Industries in which management costs area low percentage of operating costs are less likely to be sensitive to high waste management costs. Even for generators whose current costs are not large, the threat of future liabilities may raise the specter of enormous long-term costs of waste management. But these liabilities are usually speculative and may be discounted in terms of present dollar value or maybe given less importance because management believes that changes in government policy may reduce them.[16]

On a more day-to-day level, the accounting procedures companies use for waste management costs affect the ways in which waste reduction decisions are made. Particularly important is the degree to which companies assign waste management costs (including liability costs) to the processes or plants which produce the waste. If a company has an onsite waste treatment plant with its own budget and all processes within the plant send their waste there and are not accountable for that management cost, process engineers and supervisors have little incentive to examine their operations for waste reduction opportunities. If, on the other hand, companies trace waste back to the processes generating it and incorporate waste management costs into the process manager's budget, the people who are intimately familiar with the process have an incentive to search for ways to reduce the amount of waste generated. Thus, to the extent that *total* waste management costs are strictly accounted for as *production* costs, they will act as incentives for investing in waste reduction.

Accounting procedures may also influence the probability that waste reduction measures will compete successfully for limited company funds. The way in which return on investment is calculated and the extent to which and the way in which waste management costs are incorporated into investment calculations will influence the amount of capital investment and, therefore, the kinds of waste reduction measures a company is likely to take.

This competition occurs on two levels. First, environmental programs, in general, and waste reduction programs, in particular, must compete with all other potential uses of an operation's limited capital funds. If a firm is faced with choosing between investing in a new product line, purchasing less labor-intensive equipment for its current processes, or making process alterations which will reduce waste, a firm may calculate that it will get a better return on investment from one of the first two options than from the waste reduction option,

Further, most operations have a single budget for environmental programs and this includes waste reduction. In such operations waste reduction must compete with waste management and compliance programs for funds and attention. Waste management options are often difficult to compete with when reasons for implementing them are painfully clear, as in a firm that is being threatened with citations for noncompliance with pollution control regulations. In addition, waste management presents a clearer, surer investment option in the eyes of most generators who see off-the-shelf

[16]One example of a change in government policy which may reduce liability is EPA's current reexamination of the definition of hazardous waste under RCRA. Some generators may believe that their wastes will not be hazardous under the new definition and may therefore not be willing to invest much effort in reducing their generation.

pollution control equipment and operations changes as proven. Waste reduction options are usually newer, methods may be unproven, and the results unpredictable,

The uncertainty about the costs of implementing waste reduction measures is critical to decisionmakers who want reliable figures on waste management savings, labor, capital and operating costs, as well as on the costs or savings in raw materials resulting from the waste reduction measure, However, changes at the front end of an operation tend to have ripple effects throughout, and quantifying all of these effects and their costs or savings can be extremely difficult. Isolating waste reduction may result in smaller benefits, while seeing it as part of a broader innovation or change in production may increase its costs, Clearly, there are ways to make waste reduction appear more or less attractive economically. Since, as noted above, decisionmakers in business tend to avoid unnecessary risk, the difficulty in coming up with firm figures on waste reduction investments handicaps them in competing for limited company dollars.

Government Regulations

Despite widespread noncompliance and complaints about ineffectiveness, environmental regulations significantly influence the ways businesses make decisions about waste. These regulations may be of two types; they may directly require that business take action or they may affect the environment in which businesses make decisions. Probably the most influential government measures to date have been of the latter variety, such as the joint and several liability for Superfund sites and the enactment of land disposal bans in the 1984 RCRA Amendments. Both of these measures hit directly at the financial calculations which determine waste-related decisions.

Industry responses to government requirements for environmental action vary with the size and structure of the company as well as with more intangible factors like plant management and corporate attitudes. Small companies are less likely to have the resources and personnel to keep up with all of the details of government regulation and may simply throw up their hands and hope that their small size will make them unlikely targets for enforcement, Large corporations that may have other reasons for believing that enforcement may not occur still usually have environmental compliance staffs assigned to keep track of regulations, The job of these environmental engineers, however, is environmental *compliance* and pollution control, rather than environmental protection or pollution prevention in the larger sense. This distinction bears directly on the ways in which large companies currently make decisions about waste reduction, Environmental engineers in large companies sometimes say that they have trouble getting support from management for environmental actions which are not required by regulations, such as audits to trace waste to processes,

Current environmental regulations may have handicapped waste reduction in several ways, First, the existing elaborate framework of pollution control laws has become the center of the environmental protection arena. Control laws are both established and—in theory, if not always in practice—enforceable, The waste minimization program set up in the *1984* RCRA Amendments is both new and voluntary. It is hardly surprising that companies concentrate their efforts on avoiding penalties and installing proven and accepted methods of environmental protection rather than investing resources in voluntary programs they know little about.

Second, the current waste minimization program under the 1984 RCRA Amendments is not designed to give companies strong incentives to promote waste reduction. As discussed elsewhere, the language of the national policy statement in the amendments makes clear the primacy of waste reduction but subsequent sections of the statute give equal attention to good waste management. In the regulations promulgated under the amendments, the concept of waste reduction as defined in this study and in the national policy statement has all but disappeared, Under the regulations, waste minimization appears to mean any measure that avoids landfilling hazardous materials. People in industry are, not surprisingly, reacting to the regulations rather than the policy statement and have adopted this latter interpretation of waste minimization as the basis for their efforts.

The extent to which this program will prompt extensive action in large corporations is not yet clear, Preliminary signs suggest that the amendments are affecting corporate thinking—that they are bringing waste minimization and better waste *management,* if not waste reduction,[17] to the attention of corporate decisionmakers in an unprecedented way. The amendments have also provided environmental engineers with a justification for implementing waste reduction measures or, at least, collecting waste reduction information. On the other hand, it is clear that these voluntary efforts under RCRA will focus on minimization of RCRA wastes; they are unlikely to aim at multimedia waste reduction. How significant or far-reaching these voluntary actions will be is unclear and is likelv to remain so since, as discussed elsewhere "in this report, no meaningful data are being collected on current waste reduction efforts.

[17] See chs. 1 and 5 for discussions of the differences between waste minimization and waste reduction and whv thev are important to OTA's study

HOW MUCH WASTE REDUCTION IS POSSIBLE?

Why People Ask This Question

In view of the very large number of targets for waste reduction, the many ways to achieve it, and the lack of data, it is impossible to forecast future levels of waste reduction even approximately. Nevertheless, from a public policy perspective it would be useful to get a handle on the upper technical bound for waste reduction. No matter how much waste reduction may already have been accomplished, unless the potential amount is known, there is always uncertainty and even suspicion about the significance of the effort. That is, the degree of unrealized waste reduction potential is seen as the definition of the problem; the higher the potential, the stronger the case for doing something (e. g., government setting new policy or industry spending more money). Although this might make some sense on environmental grounds, effective waste treatment is also an option and it may not always make sense to reduce wastes at a specific site. A point of diminishing returns is possible for waste reduction.

For example, when the polymer polyethylene was first manufactured in the early 1940s the amount of waste was 80 to 90 percent of the original raw materials. The waste is now less than 5 percent. But this does not necessarily say anything about how much of the current waste might be reduced nor whether its chemical nature, amount generated, and the way it is managed or released at specific sites results in environmental risks that might be reduced or avoided, Further waste reduction may or may not make environmental or economic sense, but that cannot be known unless the possibility of waste reduction is seriously examined.

Why Forecasts Are Uncertain

Even if general economic factors are excluded, estimates for technically and economically feasible amounts of waste avoidance and reduction in the future are uncertain because:

- There are too many industrial processes and wastes—certainly tens of thousands—to examine each in detail.[18]
- Waste generation and reduction are plant- and process-specific, but the limited waste generation data available are aggregated over many processes and usually over a diversity of plants and companies.
- It is not known how much waste in all (*not* just RCRA waste) was and is now being

[18] Chemical Waste Management, Inc., has identified nearly 100,000 different wastes in its waste management business.

generated; therefore, reduction cannot be documented.

- There is no base year for all data.
- It is difficult to predict what changes in production technology and products will occur over a broad range of industry for reasons unrelated to waste, and such changes can substantially change the nature or quantity of waste, or both.
- Considerable amounts of wastes (particularly as regulated under the Clean Water and Clean Air Acts) are legally sanctioned and continued implementation of environmental programs will create more waste (e.g., pretreatment standards under the Clean Water Act increase the generation of solid, hazardous wastes).
- Many regulatory, enforcement, and judicial actions that affect the economic feasibility of and perceived need for waste reduction may occur.

Limited Expertise Problem

There is always an important systematic error in any estimate of future waste reduction. Considering the range of technical approaches, the best any analyst will be able to do is to make estimates for the techniques that are easiest to use, such as in-process recycling. Much more difficulty will be encountered in estimating waste reduction for the other approaches. No person or group, either outside or inside a company, is likely to have detailed information about enough industrial technologies and processes to be able to estimate the results of all or most of the changes that may, to varying degrees, reduce waste. Consequently, estimates, even by those in industry responding to a survey or those studying the technical literature and making professional judgments, are likely to be on the low side and to vary greatly. In most estimates there is little information about the approaches to waste reduction that were considered and how they were applied to industry sectors or waste streams.[19]

Facility Siting Bias

Some States have made estimates of future waste reduction, often in association with attempts to site waste *management* facilities, Such estimates are made in the context of the current system; that is, a predominantly voluntary approach to waste reduction which is not being implemented as if it had primacy over pollution control, In the context of siting, little attention has been given to the potential importance of waste reduction in: 1) reducing the need for more sites, and 2) assuring the public that everything has been done to reduce the number of sites that will be needed. State agencies sponsoring these estimates often have a bias toward siting waste management facilities, Moreover, the forecasts are based on surveys of generators who send large amounts of waste offsite. Therefore, they are likely to err on the low side; that is, to underestimate the amount by which waste reduction may reduce the need for waste management facilities. Also, waste generators naturally want to keep waste management costs low, which can be accomplished in part by ensuring enough offsite capacity,

Diffusion of and Access to Waste Reduction Technology

Waste reduction in the future will be affected by the extent to which information and products are diffused throughout industry and are available to companies. For the most part, the country is in the early stages of transferring waste reduction technology. Indications of this process are:

- Companies that have been successful at waste reduction are making their knowledge and expertise available to other divisions and are sometimes profitably selling the technology to other companies.
- State programs generally focus on efforts at transferring information and providing

[19] A good example of this problem is the information in U.S. Congress, Congressional Budget Office, *Hazardous Waste Management: Recent Changes and Policy Alternatives* (Washington, DC: U.S. Government Printing Office, May 1985). Information given on changes in waste generation due to waste reduction is misleading because limited information prevented the full range of techniques from being considered, although this was not very clearly stated. Tbus, the total waste reduction amounts reported are systematically low.

technical assistance, particularly to smaller companies.

- There are increasing numbers of conferences, workshops, awards presentations, publications, and courses helping to spread information.
- More information is becoming available from other nations where there sometimes is a longer history of interest in low-waste or pollution-free technologies.
- Some companies in the waste management industry are beginning to develop commercial ways of developing, applying, and transferring waste reduction technology.
- Financing is becoming available for waste reduction activities, although financing is likely to remain a problem for many firms.

Under current Federal and State programs there will not be a very comprehensive or efficient transfer of technology and information in the near future, Because waste reduction technology is evolving from simpler to more complex and process-specific techniques, it will become more difficult to transfer. In-process recycling and plant operations add-on techniques, currently emphasized, are the easiest to transfer across companies and industries. One other type of waste reduction is also readily transferable; that is, the substitution of certain raw materials to common manufacturing operations. An example previously mentioned is the replacement of solvent-based inks with water-based ones; some printing plants have essentially eliminated their generation of spent solvents in this manner. Companies that manufacture products used by other companies as raw materials will increasingly commercialize new products with waste reduction advantages for sale to U.S. industry and in foreign markets.

Competition From Waste Management Alternatives

The degree to which waste technologies are implemented in the future will depend strongly on alternative waste management methods. Different approaches to waste reduction will, to some extent, compete with each other, and the competition between waste reduction and the more traditional waste management approach will persist. Current corporate efforts to market more effective waste management technologies and pollution control techniques and to site new waste management facilities are not necessarily consistent with fostering waste reduction at the source. Indeed, in the *1984* RCRA Amendments there is some conflict between the goal of waste minimization and that of waste reduction.

Waste minimization is generally taken to mean reducing the amount of waste that is land disposed (see ch. 5). Lack of data and imprecise forecasts contribute to the attitude that environmental protection means only *better waste management.* **Although it is better to treat wastes to render them permanently harmless than to use any form of land disposal, it is still better to avoid or reduce the generation of hazardous waste, if it is technically and economically feasible.** *Any* waste management activity will pose some environmental risks and require regulation. There is no fundamental reason to believe that waste *management,* which involves repeated spending, is always or even usually more economical than waste reduction, although it may be in some circumstances. It is because waste management has been inexpensive that there often has seemed to be little point in cutting costs by not generating wastes to begin with. For some time to come, waste reduction, particularly by more costly methods, will face competition from waste treatment and disposal technologies. (Most available data reveal no sign yet of a major decrease in the use of land disposal,) This may change, however, because of the closure of onsite waste management facilities which have not been able to comply with new RCRA requirements which have not been able to comply with new RCRA requirements, increased production levels, and uncertainties about how some of the *1984* amendments to RCRA—notably the land disposal bans—will be implemented.

Waste management will remain a viable alternative for the foreseeable future. Both government and industry will make many decisions affecting the competition between waste reduction and waste management, and these are nearly impossible to forecast.

Review of Current Forecasts

Table 3-4 summarizes information and comments about several State efforts to obtain information on waste generation and reduction, The following observations can be made about the State information:

- Except for a downturn in 1982 to 1983, probably due to the economy, aggregated State data now show a trend toward an increase in hazardous waste generation because of economic growth and other factors,
- States are preoccupied with the issue of siting hazardous waste management facilities for wastes shipped offsite.
- Analyses of waste reduction are usually done for offsite wastes. These are only about 10 percent of the Nation's total generation; they may, however, represent high-hazard wastes.
- Although it is difficult to compare State studies, estimates of waste reduction for several States using similar methods vary significantly (Missouri, 4 percent; New Jersey, 7 percent; New York, 16 percent; Pennsylvania, 23 to 27 percent; Minnesota, 47 percent).[20]
- No attention has been given to non-RCRA wastes.
- Estimates for increases in hazardous waste generation due to increased water pollution control are relatively low but are only for wastes shipped offsite. They may be misleading because most pretreatment will be done onsite by large waste generators.
- No data are given for pastor future plant-specific waste reduction.

In a Congressional Budget Office (CBO) study the data given indicate a total of 18 percent RCRA hazardous waste reduction nationwide over the period 1983-90. However, most of this —12 percent—is accounted for by volume reduction by dewatering, a practice OTA considers not environmentally significant. The remainder is accounted for by material recovery, but much of this is probably offsite and not within OTA's definition for in-process recycling. The CBO study did not consider the full range of techniques because of a lack of information. This is an understandable limitation common to most analyses, but it is not always made clear. Thus, the total waste reduction amounts reported are systematically low with regard to the reduction of waste at the source.[21]

A survey of companies for the Tennessee Valley Authority in 1984 found that by the year 2000 total RCRA waste reduction could be 11 percent for wastes which could be incinerated and 33 percent for wastes normally deposited in landfills.[22] The study used 1984 as a base year and kept production levels constant; a very small sample of companies were surveyed.

Although for most cases it is, *in principle, impossible* to reach zero waste generation, in OTA's survey, which stressed technical feasibility and a broad definition for hazardous waste, 11 percent of the respondents felt that 50 to 75 percent reduction was possible through a variety of efforts; 25 percent of the respondents felt that 25 to 50 percent was possible, and 59 percent felt that less than 25 percent reduction was possible. But, again, such estimates may be low.

[20]One possible explanation of this rather large range of estimates is that the types of industries vary greatly among these States, but other factors may also be important, such as varying definitions and varying perceptions by survey respondents of what is possible and what is *likely* in the near term.

[21]Congressional Budget Office, *Hazardous Waste Management: Recent Changes and Policy Alternatives,* op. cit. Another aspect of this study is that it is essentially an analysis based on modeling. Although the total amount of waste generation obtained is in agreement with other data sources, none of the other detailed data which deal with the distribution of waste generation among waste types, industries, management technologies, or States are in agreement with other data sources.

[22]Battelle Columbus Laboratories, "Report on Hazardous Waste Management Needs Assessment, " June 1984.

Table 3-4.—State Information Related to Waste Reduction

ILLINOIS: The State Environmental Protection Agency collects data on generation of hazardous waste from all generators:

Millions of gallons		
1982	1983	1984
547.3	460,7	526.2

The agency does no analysis of these data for waste reduction.

SOURCE" Illinois Environmental Protection Agency, *Summary of Annual Reports on Hazardous Waste for 1982,1983,* 1984, September 1985

MICHIGAN: State Department of Natural Resources data on generation of RCRA hazardous waste:

1983 425,000 tons

The Department estimated 6 percent maximum increase in generation from 1980 to 1990 attributable to economic development. After other factors were considered (waste reduction *not* among them) it is said that a 10-percent increase compared to 1983 is reasonable for existing generators. Very little consideration of waste reduction.

SOURCE Michigan Department of Natural Resources, *Hazardous Waste Management in Michigan,* March 1984

MINNESOTA: The Waste Management Board has compiled data principally to aid in estimating the need for a hazardous waste disposal facility in the State. The Board's data on generation of industrial hazardous waste (RCRA waste only):

1984 123,000 tons

Of this total 31,000 tons is managed onsite. Estimates of waste generation in the years 1990 and 2000 are based on combined effects of economic growth and waste reduction efforts. Detailed economic growth rates for industry segments are given. Estimates of waste reduction for the year 1990 are based on 97 estimates of reduction by waste type and industry segment. From 1984 to 1990 waste generation is projected to increase to 153,000 tons because economic growth outweighs waste reduction (no waste reduction figure given). For the year 2000, a weighted average of percent reduction figures given for waste types (without industry segments) yields an estimate of 47 percent reduction relative to 1984. Waste generation in the year 2000 estimated to be 126,000 tons due to additive effects of slower economic growth and increased waste reduction. Only RCRA wastes considered. Analysis also given for reduction of waste treatment residuals.

SOURCE Minnesota Waste Management Board, *Estimate For Need,* 1985

MISSOURI: Study for the Environmental Improvement and Energy Resources Authority focused on the possibility of a State owned hazardous waste treatment and resource recovery facility. Generation data therefore includes only wastes shipped off site:

1982	1983	1987	2002
57,000	56,000	61,000	85,000 tons

Projections for future years are based on economic growth, source *reduction,* and projected additional RCRA waste from pretreatment (10,000 tons in 1987 and 13,000 tons in 2002). Source reduction for 1987 is estimated at 4 percent (2,000 tons); no further reduction is projected thereafter (3,000 tons in 2002), even though it is stated that "much more waste reduction may occur by 2002. " Estimates are based on reduction of eight wastes in seven industries.

SOURCE" Environmental Improvement and Energy Resources Authority, *Missouri Hazardous Waste Treatment and Resource Recovery Facility Feasibility,* January 1985

NEW JERSEY: The Facilities Siting Plan focuses on siting commercial hazardous waste management facilities and, therefore, uses data on wastes shipped off site (manifest data):

1981	1982	1983
412,000	344,000	403,000 tons

Projected waste reduction for 1988: 33,000 tons. This is relative to 460,000 tons used as a composite average for 1981-83 plus the effects of economic growth. The result is a waste reduction estimate of 7 percent over about a 6-year period, based on estimates for 30 industry-waste type possibilities (4 of which were increases). No similar analysis is given for waste generated and managed onsite (1 1,767,000 tons for 1983, based on 242 annual reports). Potential increase in hazardous waste due to new actions under Clean Water Act: 33,000 tons. No consideration of reduction of non-RCRA wastes.

SOURCES New Jersey Facilities Siting Commission, New Jersey *Hazardous Waste Facilities Plan*, March 1985

Table 3-4.—State Information Related to Waste Reduction—Continued

NEW YORK: The State Department of Environmental Conservation uses the following generation data on manifested, off site RCRA wastes for siting purposes:

1982	1983
285,000	251,000 tons

Projections are made as follows for other years, based on consideration of many factors including economic growth and source reduction, but no details are given:

1984	1988	1994
280,000	308,000	365,000 tons

For one 1986 scenario involving high waste reduction, an additional degree of waste reduction (for RCRA wastes only) is specified above that presently planned by industry; reduction there is projected to be 48,400 tons, or 16 percent, of the 1988 base. This is based on estimates for 34 waste types (no industry segment breakdown), of which 24 had no change.

SOURCE New York Department of Environmental Conservation, *New York State Hazardous Waste facilities Needs Assessment,* March 1985,

NORTH CAROLINA: The Governor's Waste Management Board uses data for RCRA hazardous waste shipped off site because of its interest in siting:

1981	1982	1983
48,650	42,800	52,550 tons

No analysis of data for waste reduction.

SOURCE: Governor's Waste Management Board, *Hazardous Waste in North Carolina,* undated

PENNSYLVANIA: Data on waste generation compiled by the Department of Environmental Resources are used for siting and therefore focus only on manifested, off site RCRA waste:

1981	1982	1983	1984
774,000†	485,000	598,000	639,000 tons

Projected waste reduction for 1990: 181,000 tons (expected case) and 211,000 tons (high *source reduction* scenario) relative to composite (1982-84) base of 661,000 tons, accounting for economic growth only. That is a reduction of 23 and 27 percent over about a 5-year period. These figures are based on estimates for 104 industry-waste type possibilities (16 of which had no change). Data may be misleading as *source reduction* may include actions that reduce waste shipped off site, but sti II generated. For waste generated and managed onsite (4,200,000 tons for 1983), no similar analysis of reduction is given. Potential increase in amount of hazardous waste generated due to new actions under Clean Water Act estimated at 4,000 tons. No consideration of reduction of non-RCRA wastes.

†Calculated by OTA on basis of reported data.

SOURCE Pennsylvania Department of Environmental Resources, *Pennsylvania Hazardous Waste Facilities P/an,* draft, November 1985

WISCONSIN: Department of Natural Resources RCRA hazardous waste generation data:

1979	1984
300,000 to 500,000	125,000 tons

Change attributed to waste reduction without detailed analysis of other factors. Goal of 100 percent reduction and recovery for 8,000 tons land filled in Wisconsin (another 26,000 tons landfilled in other States) in 1984, but now Wisconsin has no landfill capacity for hazardous waste.

SOURCE: Wisconsin Department of Natural Resources, *Wisconsin Waste Reduction and Recovery Plan,* August 1985

CONCLUSIONS

There are technical reasons for concluding that it is not possible to accurately estimate future waste reduction in terms of the maximum technologically possible. Indeed, the technical possibilities for waste reduction are rapidly changing. Moreover, estimates are likely to be low. People outside of industry are not likely to be sufficiently familiar with industrial operations to make good forecasts. People in industry are unlikely to be able to assess the full range of waste reduction techniques possible—and not merely likely—in the near term *and* long run.

The technological potential for waste reduction is substantial, although it is quantifiable only in the most approximate terms, across both industries and waste types. The conclusion that there are many opportunities for waste reduction in the future rest on evidence that **industry has not yet been sufficiently motivated, has not had enough time to do more than get started, and has only begun to exploit the possibilities technology offers.**

It might be more useful to *focus on a waste reduction goal rather than to try to calculate how much is possible.* For example, a goal of perhaps 10 percent annually might do much to stimulate and draw more national attention to waste reduction. This goal is consistent with results obtained so far and with goals used by some companies. If waste reduction is to offset increases in waste generation from economic growth and increases from more wastes becoming regulated under pollution control programs, then such a goal maybe needed just to hold the line on requirements for hazardous waste management.