Hazardous Wastes Technology Is Available

Eliminating their production is the ideal, but recycling, chemical, and biological degradation are good alternatives

Suppose that, after you've finished reading this magazine, you had two choices for its disposal: you could put it in the garbage can for disposal with the rest of your trash, or you could mail it to a special collection center at a cost of 50 cents. The choice, for most people, is obvious. Now suppose that the ink with which it is printed contains a contaminant that might harm the environment if it escapes from a conventional sanitary landfill, but that can be detoxified at the special collection center. Suddenly the choice becomes much more difficult. Is the potential for harm to the environment of greater importance than the extra $26 per year in mailing costs? Suppose the mailing cost is $2 per issue and the scientist in the laboratory down the hall, who doesn't mail in the magazines, can get a competitive advantage over you with that extra $100 per year?

This is the second of four articles about the disposal of hazardous wastes. The third article will discuss deep-well injection and incineration, the fourth solidification and secure landfills.

That, in simplified terms, is the moral and financial dilemma that has in the past faced generators of hazardous wastes. Acceptable ways to deal with such wastes have been available for many years, and the number of alternatives continues to grow, but the cost of such alternatives is almost always much greater than that of less desirable methods. Disposal of hazardous wastes in an unsecured landfill might cost as little as $5 per ton, for example, whereas a desirable alternative such as incineration might cost as much as $300 per ton. In a highly competitive business atmosphere, the one company in an industry that adopts acceptable disposal procedures does so at the risk of being priced out of business.

The new regulations on disposal of hazardous wastes issued by the Environmental Protection Agency (EPA) under the provisions of the Resource Conservation and Recovery Act (RCRA) promise to ease those dilemmas for many companies. By forcing all companies within an industry to use acceptable disposal techniques, the regulations remove any competitive disadvantage associated with such use. The chief problem remaining now for the industries is selection of the most advantageous disposal technique from among the many available. The chief problems for the government are enforcement of RCRA and overcoming citizen resistance to disposal facilities. Everyone seems to agree that disposal facilities must be built, but no one wants one near them. This citizen opposition has greatly complicated the construction of landfills, incinerators, and other facilities and has, perversely, contributed to the continuation of less acceptable disposal practices at facilities that are already in existence. Even the best technology is no good if it cannot be put into use.

Clearly, the ideal solution to the hazardous wastes problem is to change industrial processes so that hazardous byproducts are not produced or, if that is not feasible, to extract hazardous materials from the waste streams and use them as raw materials. In the past, the cost of recovery of such materials has generally been much greater than the cost of new materials, and this option has been little used. The increased costs of disposal mandated by RCRA, though, provide a strong incentive to reduce the waste load and recover as much of the wastes as possible. This pressure for recovery is abetted by the increased cost of raw materials, particularly petrochemicals.

Joan Berkowitz of Arthur D. Little, Inc. cites one manufacturer who, a short time ago, was anxious to dispose of distillation residues from the production of ethylene glycol. When asked about the residues recently, however, his reply was, "What wastes?" Another good example involves recovery and reuse of polyvinyl alcohol, an agent used in the textile industry for sizing yarns before they are woven into textiles. Previously, the alcohol was scoured from the cloth before the cloth was dyed, and was released into the environment. Investigators at J. P. Stevens Company Inc., Clemson University, Gaston County Dyeing Machine Company, and Union Carbide Corporation developed a hyperfiltration process for recovery of as much as 96 percent of the alcohol from the effluent stream. This, says Stevens, prevents about 2.2 million kilograms of nonbiodegradable polyvinyl alcohol from being released into the environment each year.

In general, recovery techniques are both process- and material-specific, so that a generalized discussion is all but impossible. Encouraging such recycling is the number one goal of EPA, however, says deputy assistant administrator Steffen Plehn, and the agency hopes that such processes could reduce the total hazardous waste load by as much as 20 percent.

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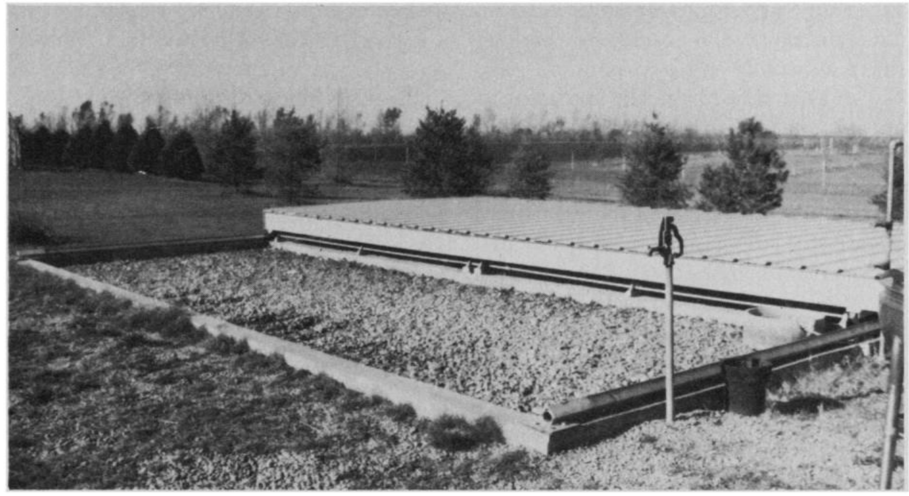
Even if the company that generates the wastes is not able to use them, they might be useful to someone else. Waste solvents produced by the electronics industry, for example, are of higher quality than virgin materials used in many processes less sensitive to impurities, Berkowitz says. Competitiveness and secrecy within industry, however, make it difficult or impossible for one company to know what is available from another. One way to overcome this problem is with a waste exchange or clearinghouse in which available materials are listed without identifying the source. Until about 1975, the only waste exchange in this country was operated by the St. Louis Regional Commerce and Growth Association, although the concept was fairly common in Europe. In that year, EPA commissioned a study of the concept by Arther D. Little, concluded that it was viable, and began promoting the formation of such exchanges.

As many as 40 exchanges were established within the next few years, but many of them failed after a short period of operation. A major reason for failure, according to Harry Trask of EPA, was the involvement of state and local governments in their operation. Many companies simply refused to provide information to the exchange for fear that it would end up in what they considered "unfriendly hands." In many cases, though, the organizing group also did not follow through with the necessary effort to make the exchange a success.

Today there are about 20 clearinghouses in this country and one in Canada. They are operated by trade associations, chambers of commerce, universities, and—in states where confidentiality can be maintained—by state and local governments. A few are also operated as profit-making ventures. The most common types of materials listed by the exchanges are solvents and oils, paper, wood, scrap metals, and surplus chemicals. In most cases, the clearinghouse simply provides an updated listing of available materials and forwards inquiries to the company that listed them; the exchange or purchase is then handled by the participants. In a few cases, though, most notably in a program operated by the state of California, the clearinghouses actively try to arrange exchanges or sales.

Because of confidentiality and the passive role of most of the clearinghouses, it is difficult to monitor the amount of material that changes hands. The St. Louis clearinghouse, though, estimates that about 10 to 15 percent of the listed materials actually change hands. Translating those results nationwide, EPA's Trask estimates that about 3 percent of all industrial wastes could be recycled in this fashion. The number of clearinghouses is growing by three to four per year, however. With more clearinghouses and increased pressure from RCRA regulations, EPA hopes the percentage of hazardous wastes recycled will at least be doubled by 1985.

If the wastes cannot be recycled, they can often be detoxified by relatively simple chemical treatment. Such treatment can either render the material completely innocuous or substantially reduce the volume that must be disposed of.



Pesticides and other organic materials can be degraded by aerobic microorganisms in this pit at the University of Iowa.

Like recycling, chemical treatment is material-specific, but some generalizations can be made.

The most common technique for chemical treatment, according to Alexandra Tarnay of EPA, is pH adjustment or neutralization. Pickle liquors from electroplating and other metal-finishing industries, for example, are much too acidic to be discharged into the environment. Neutralization with lime or some other inexpensive alkaline material may make them safe for discharge. Neutralization has the additional advantage of precipitating heavy metal ions in the liquors as insoluble hydroxide salts, which can be removed from the waste stream by settling or filtration. The free liquid can then be discharged and the much smaller volume of hydroxide salts disposed of in a landfill or by some other method. The iron and steel industry, for example, frequently uses neutralization and precipitation to remove iron and other metal ions from waste streams.

Oxidation and reduction reactions are also frequently used. Waste streams containing cyanides, for example, are oxidized with sodium hypochlorite or a mixture of sodium hydroxide and chlorine to produce carbon dioxide and nitrogen. Similarly, toxic chromium-VI ions in a waste stream can be reduced to less toxic chromium-III ions with sulfur dioxide. Many other materials can also be treated with oxidizing or reducing agents to render them harmless or less toxic.

The volume of waste streams can frequently be reduced significantly before disposal or further treatment by evaporation from a holding pond, vacuum filtration, or heating. Water is frequently removed from waste streams produced in the manufacture of photographic chemicals, for instance, by evaporation. So-called black and sulfate liquors from the paper industry are commonly concentrated by contact with hot flue gases before the liquids are incinerated.

Other chemical treatment processes are also useful, but are less common. Adsorption on activated carbon, for example, can be used to remove some types of organic materials from dilute waste streams. The organics can sometimes be removed from the carbon and recycled, but often both the carbon and the organics are incinerated. This technique is sometimes used in the food processing industry and to remove dyes from waste streams in the textile industry. Ion exchange chromatography can also be used to remove various ions from waste streams, but its use is limited by its relatively high cost. It is sometimes used, however, for removal of chromium ions from certain types of plating baths. The various types of chemical treatment processes together are probably used on some 5 to 10 percent of hazardous wastes in this country.

Chemical treatment can often be a more efficient process if it is performed by someone other than the company that generates the wastes. Regional waste disposal centers in West Germany and some other parts of Europe, for example, generally use an alkaline waste from one company to neutralize an acidic waste from another company. Similarly, a waste stream containing cyanide might be used to reduce chromium-VI in another waste stream. In this manner, valuable raw materials are not used to detoxify wastes, and the overall cost is cheaper. A similar approach is used by some waste disposal companies in this country, such as SCA Services Inc. of Boston, but the total amount of wastes that they treat is very small.

For many types of wastes, particularly nonchlorinated organic wastes, biological treatment is an acceptable alternative. The most common type of biological treatment is soil incorporation, also known as land farming. The spreading of organic wastes such as animal manure, crop residues, and sewage onto agricultural land to supply plant nutrients is an ancient one. Extension of the practice to other types of organic materials, however, is a phenomenon of the last 20 years, pioneered primarily by the petroleum industry. In general, the practice involves four basic steps: application of wastes onto or beneath surface soil; mixing the waste with surface soil to aerate the mass and expose the waste to soil microorganisms; addition of nutrients, when necessary; and remixing the soil and waste mass periodically to maintain aerobic conditions.

EPA recently issued proposed regulations governing land farming; these are based largely on a study conducted for the agency by David E. Ross and Han T. Phung of SCS Engineers Inc. in Long Beach, California. That study concluded that land farming is an acceptable technique for management of various types of wastes if suitable constraints are imposed. Among other things, the farmed area should be at least 1.5 meters above the historical high groundwater table; it should be at least 150 meters from water supplies; erosion potential should be minimal; and annual rainfall should be low to prevent formation of an anaerobic mire. Most important, Ross and Phung argue, the soil itself should be monitored regularly to a depth of 1 meter to detect any downward migration of trace metals or other contaminants. Previous investigators had assumed that groundwater should be monitored, but by the time contaminants reach groundwater, Phung says, it may be too late to prevent environmental deterioration.

Because of these constraints and the need for large areas of land, land farming has been most successfully practiced in semiarid regions of the west. Materials that have been successfully land farmed include sludges from paper mills and fruit canneries, sewage sludge, pharmaceutical wastes, and some organic chemical wastes. The city of Odessa, Texas, even used the technique for municipal refuse, but the amount of land required was very large and the area was very unsightly. By far the greatest amount of experience with land farming, however, has been obtained with petroleum refinery sludges.

Petroleum companies such as Exxon and Continental Oil have practiced land farming for 10 to 15 years. Typically, sludge is spread on the soil in a layer 7 to 15 centimeters thick, according to R. S. Lewis of Exxon. After water is allowed to evaporate for a few days, the sludge is disked into the soil and, if necessary, other nutrients are added. When the oil content in the top 15 centimeters of soil has been reduced to about 2 to 4 percent, another application can be made; generally, this reduction requires about 2 months. At one typical Exxon refinery in Baytown, Texas, Lewis says, sludge was applied at an average rate of 1008 tons per hectare per year. Extrapolating from these and other data, SCS estimates that about 3 percent of all industrial wastes in this country could be disposed of by land farming, at a cost of about \$5 to \$22 per cubic meter, exclusive of transportation costs. That price compares favorably with the cost of incorporation in landfills.

Land farming is not appropriate for wastes that contain significant quantities of heavy metals or other materials that are not biodegradable and that would thus accumulate in the soil. This problem might be overcome, though, by conducting the process in a closed system. Charles V. Hall and his colleagues at Iowa State University, for example, have been experimenting for more than 10 years—the last three in cooperation with EPA—with degradation of pesticides and other organic materials in a concrete-lined pit. The pit is approximately 4 meters by 8 meters, a little over a meter deep, and filled with gravel and soil; it is equipped with a cover that closes automatically to prevent precipitation from filling the basin. Aqueous solutions of pesticides or organics are simply placed in the pit; the water evaporates away and the organic component is degraded by the same types of microorganisms that are active in land farming.

> Chemical treatment can often be more efficient if it is performed on a regional basis.

In a typical warm season from May through October, Hall says, the pit can handle 6000 to 7000 gallons of waste. The system can be scaled up to handle much larger volumes of wastes, he says, and the cost should not be substantially greater than that of land farming. If the wastes contain nonbiodegradable contaminants, he adds, they will be greatly concentrated in the soil in the pit and can subsequently be conveniently disposed of. The group is now looking for more efficient microorganisms, and is studying the concentrations of volatile organics in the air over the pit to ensure that there is no hazard.

The rate of biodegradation can be speeded up if the temperature of the wastes is raised; this can be achieved by aerobic composting, says Eliot Epstein of Energy Resources Company Inc. of Cambridge. Thermophilic bacteria thrive and multiply at temperatures of 45° to 80°C in the compost piles favored by organic gardeners, and similar conditions can be achieved in an industrial setting. The principal requirements are containment, protection from precipitation, and use of a bulking agent so the system remains porous and aerobic. The economics of the process, Epstein says, depend on the cost of the bulking agent; the cost could be kept low, he adds, by using straw, ground-up waste paper, or agricultural wastes.

Decomposition of wastes in composting is significantly faster than in land farming. DDT wastes have been 64 percent degraded in as little as 50 days, Epstein says, and organophosphorus pesticide wastes in as little as 2 weeks. The system is also versatile. Tests by the U.S. Army, Epstein notes, have shown that composting can be used to degrade TNT wastes. Pesticides, phenols, and aromatics are among other materials for which the system is suitable. Energy Resources is also investigating composting of oily wastes under a contract with the U.S. Coast Guard.

Composting is already used for sewage sludge and for cellulosic wastes in the pulp and paper industry. The Blue Plains Sewage Plant in Washington, D.C., for example, now composts as much as 275 tons of sludge per day. Costs vary widely, depending on individual circumstances. Pulp and paper mills have found that the technique is cheaper than landfilling, but composting of sewage sludge costs \$30 to \$100 per ton of dry materials. Some of this cost can be recovered by selling the product as a soil conditioner, but this market may not be large.

The viability of composting for disposal of other types of materials may be demonstrated by Hoffmann-La Roche Inc. That company has been experimenting for several years with composting of pharmaceutical wastes at its plant in Belvidere, New Jersey, and is now requesting permission from the state to conduct a large demonstration project that would be the first industrial application of composting for anything other than paper products or sewage sludge. If their demonstration is successful, Epstein says, other companies are very likely to follow suit.

Recycling, chemical treatment, and biodegradation are the least controversial and most acceptable methods for disposal of hazardous wastes. Their primary advantage is that the waste material is either used or destroyed, so there is no further need for containment or monitoring. Of all disposal techniques, they alone have met little citizen opposition to siting of facilities—the recycling and treatment processes because they are more or less conventional industrial processes, and land farming because the sites have generally not been near communities. That situation could change if compost facilities sited near cities should produce noxious odors, but such a development should be preventable with care. The chief disadvantage of the techniques is that they are applicable to only a limited percentage of hazardous wastes. Despite the desirability of these approaches, other techniques must be found for the majority of wastes.—THOMAS H. MAUGH II

Isadore Singer and Differential Geometry

More an art form than a science, it is one of the "purest" fields of mathematics

Isadore M. Singer of the University of California at Berkeley is a quiet, collegial man, famous among mathematicians for his innovative work in global differential geometry, the study of properties of surfaces, often in higher-dimensional spaces. Geometers are concerned with how surfaces twist, what their shapes are, what sorts of holes are in them, what their curvatures are, and what kinds of metrics, or distance formulas, they have.

This is the third of a series of occasional articles about mathematics as seen through the eyes of its most prominent scholars.

There are relatively few differential geometers among mathematicians, partly because the field is highly abstract and partly because it requires so much background. However, differential geometry is attracting wider interest of late because it now seems to have close ties to elementary particle physics. Singer discussed these connections to physics in an interview with *Science* and explained the concepts and character of differential geometry research.

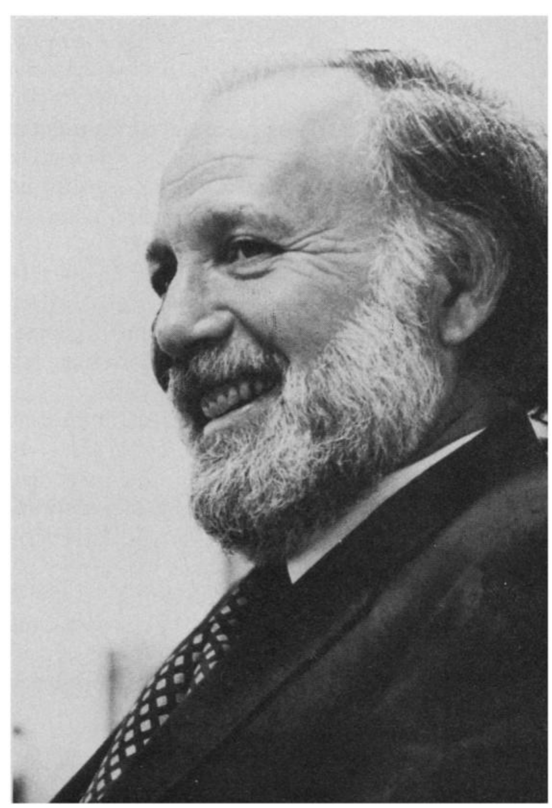
Singer is well known for his ability to explain his work to those outside his field. George Pimentel of the National Science Foundation tells a story that illustrates Singer's appeal. When Singer first came to Berkeley, he agreed to give a series of seminars on differential geometry. The first seminar was scheduled for the usual, fairly small room, but Singer drew such a crowd that the seminar had to be moved to larger quarters. Thinking the large crowd was a one-time phenomenon, the mathematics department scheduled the second lecture for the smaller room, but the lecture had to be moved again. By that time, the math department had learned its lesson and scheduled the rest of Singer's seminars for the large room.

Although Singer's appeal is genuine, the large crowd at his lectures included physicists as well as mathematicians and was probably partly due to the new interest in differential geometry among physicists. Coincidentally, or, as Singer thinks, perhaps not so coincidentally, physicists, independently of mathematicians, were led to a central concept of differential geometry, that of objects called fiber bundles. The physicists implicitly use the theory of fiber bundles in what they call gauge theories—the presently favored means of explaining the three types of forces between elementary particles: the electrodynamic, the strong nuclear, and the weak forces. It is Singer's conjecture that this convergence of mathematics and physics suggests the nature of the way the human brain works, the way people view the world. "I stand with Einstein in thinking that the explanation of the natural world is geometrical," he says.

Singer is currently exploring these connections between differential geometry and elementary particle physics as part of his long-standing interest in physics. An undergraduate physics major, he began studying mathematics because he felt he did not have the mathematical background to understand quantum mechanics and relativity. He intended to return to physics, he says, "but now physics has come back to me."

Singer is careful to emphasize that differential geometry's ties to physics are not the be-all and end-all of his field. Although exciting, they are only a small part of differential geometry. These applications, Mary Gray of The American University explains, "lend a certain cachet these days."

Fiber bundles, which are central to differential geometry, are a way of constructing abstract spaces. Each fiber bundle consists of a base space together with other spaces known as fibers. For example, the base space could be a circle and the fibers could be spikes projecting from the circle so that a spike goes through every point of the circle. The fiber bundle is the prescription, or set of rules, telling how the fibers fit together.



Isadore M. Singer

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