Recycling Hazardous Waste: An Examination of Three Options for Recovery of UC Berkeley Wastes

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Introduction

The EPA estimates that waste generators themselves treat or dispose of approximately 96 percent of all hazardous wastes on-site, most of which, 81 percent, are recycled. The top two percent of the generators produce 90 percent of the nation's toxic wastes, and do most of the recycling (Noll et al., 1986). However, for smaller generators like the University of California at Berkeley (UCB), recycling programs are perceived to be economically and practically unfeasible. Most research institutions ship wastes off-site for land disposal or incineration.

Nevertheless, there are three main reasons why UCB should consider recycling some of its hazardous wastes. Firstly, because of the increasing costs for disposing of hazardous wastes by landfill and incineration, recycling will ultimately save money. Secondly, recycling is an ethically responsible way of handling hazardous wastes, because it helps conserve resources and prevents pollution of the environment. Finally, UCB has been accused of mishandling toxic waste in the past (Herron, 1987); an innovative recycling program may help improve its image in the Berkeley community.

The particular recycling options considered in this paper were chosen because they appear to be the most promising alternatives open to UCB, as suggested by the fact that other universities are currently, or will be, exploiting these three recycling options. The first, solvent recycling, merits consideration because solvents represent a relatively large portion of the wastes generated by UCB, the recycling technology is simple, and many nearby firms commercially recycle solvents. The second option, recycling the mercury from fluorescent bulbs, may prove an efficient and inexpensive way of disposing of the bulbs, a waste that UCB does not currently treat as hazardous. (Legislation restricting the disposal of fluorescent bulbs is still in interim status and UCB has yet to formulate a disposal policy for this type of waste.) Since a unique company specializing in this type of recycling is located in the Bay Area, this seems like a recycling opportunity not to be overlooked. The final recycling option considered in this paper involves "re-using" unused chemicals. Disposing of these potentially useful chemicals is a waste of resources that could be avoided. Informal efforts to redistribute unused chemicals already exist on campus and the establishment of a more formal system for handling such wastes would increase the efficiency of these exchanges.

Past Studies

No research examining recycling of hazardous wastes as an alternative for UCB or other univerisities has been published, although Sanders (1986) presents a general survey of waste disposal practices of academic labs nationwide. Much has been written about recycling hazardous chemicals produced by industries, and many of these studies provide a general background on the topic. Some articles have described recycling practices of industry nationally (Noll et al., 1986). Other nationally-oriented examinations have focused on the recycling of particular waste types (Blaney, 1986). Similar investigations have been done specifically for Californian industries, considering both general recycling technologies (Stoddard et al., 1981), and those specific to particular waste streams (Radimsky et al., 1983). In addition, the California Department of Health Services (DOHS), in an effort to encourage recycling of hazardous wastes, publishes a yearly Waste Exchange Newsletter/Catalog, as well as a yearly listing of permitted industrial recyclers of hazardous waste.

Background

California is one of six states that have made a substantial legislative and executive effort to encourage the recycling and treatment of hazardous wastes (Gordon, 1986). The California program can be divided into three distinct parts. The first part of California's program involved assessing fees on land disposal of hazardous wastes, which helped close the cost gap between landfilling and alternative treatment of these wastes, starting in 1982 (Davis, 1984). The second part of the program banned various types of wastes (cyanides, toxic metal wastes, strong acids, PCB-containing liquids, and halogenated organics) from land disposal. These restrictions were phased in over a period from June, 1983 to July, 1985. Finally, California has encouraged the construction and use of commercial recycling and treatment centers by offering such firms low interest loans, by publishing the Waste Exchange Newsletter/Catalog, and by examining generators' waste streams to determine if they have potentially recyclable wastes (Davis, 1984).

More recently, the EPA has also started to encourage alternative treatment by banning certain hazardous wastes from land disposal, beginning with a ban on spent solvents on November 8, 1986. This is part of a program that will ban all hazardous wastes from land disposal by May, 1990, except those wastes for which sufficient alternative treatments cannot be developed.

The Office of Environmental Health and Safety (EH&S) of UCB, which is responsible for collecting and disposing of the campus' hazardous waste, has responded to these new regulations by landfilling less waste and sending increasing amounts for incineration. EH&S's waste disposal personnel devoted most of their energy over the past several years towards meeting changing legal requirements for waste disposal and, as a result, they have not yet fully explored recycling options (David Belk, pers. comm.). At present, EH&S sends only waste oil and mercury for off-site recycling. Collecting and pooling sufficient quantities of chemicals to warrant further recycling efforts is difficult, because the University produces many different kinds of wastes, usually in very small and irregular quantities. Factors compounding this collection problem include: EH&S's very limited storage space, a generator's permit setting a 90-day limit on the storage of chemical waste, and a lack of the funding necessary for the initial set-up costs of recycling programs.

Methods

Each of the three recycling options this paper investigates is considered separately. Solvent recycling is examined by initially describing EH&S's current disposal methods, and the types and amounts of recyclable solvents EH&S receives. The problems associated with pooling a large quantity of a particular solvent are then discussed, with acetone used within the College of Chemistry presented as an example. Then the possibility of distilling solvents on campus is explored by describing regulations concerning recycling and the equipment necessary for solvent distillation. Finally, the requirements and costs of sending solvents for off-site recycling are considered.

Recycling mercury from fluorescent bulbs is analyzed in a similar manner. Regulations restricting fluorescent bulb disposal are reviewed, the quantity of bulbs used by UCB is estimated, expenses of acquiring equipment necessary to prepare bulbs for recycling are detailed, and the costs of disposal at an off-site recycler are calculated.

Finally, the possibility of recycling unused and partially used chemicals is examined. First, existing informal efforts to exchange these chemicals are outlined, then more formal efforts on other university campuses are discussed and, lastly, requirements for setting up a formal waste exchange system at UCB are considered.

Data

Solvent Recycling: EH&S presently receives solvents from various departments on campus in one-gallon glass bottles or even smaller containers. These bottles may contain a single solvent or may be mixtures of solvents. Currently EH&S cannot pour the solvents into the 55-gallon drums they are shipped in, because it does not have proper facilities for solvent pouring, which include walk-in fume hoods and special respiration masks. Such facilities may soon be made available to EH&S staff at Lawrence Berkeley Laboratories. Presently, however, EH&S's solvent waste-hauler, Exeltech, uses its mobile solvent pouring facilities to transfer the solvents into 55-gallon drums, and then takes them to a disposal company of Exeltech's own choosing, usually Romic Chemical Corporation in East Palo Alto. Romic then transfers the solvents from drums to tanker trucks, and then ships them out-of-state for incineration (Stephen Burger, pers. comm.). Disposing of a single 55-gallon drum of solvent waste by this method costs EH&S approximately $505 (David Belk, pers. comm.).

Many of the solvents EH&S sends for incineration may be recyclable. These are listed in Table 1 by solvent type and number of pounds disposed of during 1986. The solvent grade used varies from commercial to pharmaceutical, depending on the lab, but because of the great cost of high grade chemicals, solvents used in bulk are generally of a lower grade. As Table 1 indicates, no solvent was collected in quantities greater than 933 lbs. (ethyl acetate), or approximately 117 gallons.

The quantities of solvents listed below may not accurately represent the amounts used on campus, as some solvents are not disposed of through EH&S. Acetone disposal by the College of Chemistry may be taken as an example. During the 1985-1986 academic year, the College of Chemistry ordered over 3184 gallons of acetone (College of Chemistry, 1986), but EH&S disposed of less than 8 gallons of acetone for the College of Chemistry during 1986 (EH&S, 1986). Although the time periods for ordering and disposal do not exactly coincide, and while some acetone may have been disposed of through EH&S as mixed organic solvents, it seems likely that a significant amount of acetone was dumped down the drain. In fact, in an examination of drain disposal of chemicals on campus, Janine Young (this report) asked seven chemistry labs to estimate the quantity of acetone they dump down the drain within one month. These labs all estimated that their drain disposal of acetone fell somewhere in the range of 1-2L per month. Assuming an average of 1.5L per month for each of the approximately 270 labs in the College of Chemistry (Edward Dutto, pers. comm.), approximately 1,100 gallons of acetone is dumped down the drain each year by the College of Chemistry. (This is a very rough estimate because lab sizes and rates of acetone use vary.)

type of solvent	quanitity in lbs.
acetone	806
benzene	224
ethanol	119
ether	125
ethyl acetate	933
hexane	216
methanol	693
N-butyl acetate	242
paint thinner	741
phenol	247
toluene	105
xylene	135

Table 1 Recyclable solvents disposed of by EH&S in 1986. (EH&S, 1986)

Two other major outflows of acetone from the College of Chemistry exist. Because acetone is a highly volatile solvent, a substantial amount of the acetone used evaporates. The yearly rate of evaporation would be exceedingly difficult to estimate and no attempt to do so is made here. In addition, EH&S disposes of, at most, a few hundred gallons each year (judged by considering Chemistry's acetone and mixed solvent disposal through EH&S for 1986). Nevertheless it seems a reasonable conclusion that a considerable amount of acetone must be dumped down the drain, and this poses problems; not only does dumping acetone down the drain reduce the quantity of solvent available for recycling, hindering the development of a recycling program, but it violates the EPA regulations banning acetone from drain disposal (Title 22, article 2, sec. 66300 and article 9, sec. 66680).

The College of Chemistry initiated a new solvent collection process on March 1, 1988 (Edward Dutto, pers. comm.). Previously, those individuals responsible for waste collection in the College picked up solvents in one-gallon or smaller containers upon request. Now, however, the College supplies each lab with two one-gallon containers, one each for halogenated and non-halogenated solvents, and makes regular solvent pick-up runs, as frequently as twice each day if necessary. Thus, setting up an acetone-pooling system would involve supplying and picking up a third one-gallon container, for acetone only, from each lab.

For UCB to recycle chemicals on campus, it must first comply with state and federal regulations regarding recycling. Apparently, this would not be difficult. State regulations designate that "recyclable material is exempt from regulation ... if the material .... is recycled and used at the site where [it] was generated" (California State Health and Safety Code, Section 25143.2, part c.1). The bill also states that such exemptions are superseded by any EPA regulations regarding the material. The EPA regulations specify that the recycling process is not regulated (Title 40, Section 261.6, part c.1). As long as UCB continues to comply with the regulations governing their generator status, it can recycle hazardous wastes without a permit.

The simplest and most effective method for recycling solvents is fractional distillation. Distillation involves the separation of two or more components of a mixture by vaporization and recovery of that vapor. Fractional distillation "utilizes a series of liquid vapor equilibria inside a vertical tower to provide a vapor which has progressively higher concentrations of the most volatile component" (Blaney, 1986). The very high volatility of solvents makes them ideally suited for this separation method.

Some solvent distillation already occurs within the College of Chemistry. The College has solvent stills set up in 10-20 fume hoods. Researchers may use these stills to purify low-grade solvents or to recycle used solvents. The amount of solvent distilled through these systems is limited by fume hood space and the large energy costs of operating the stills (Edward Dutto, pers. comm.).

There are commercially available fractional distillation units designed specifically for recycling spent solvents. Recyclene Products, located in South San Francisco, sells solvent stills ranging in cost from $5,000 to $20,000. Recyclene Products' machines recycle to a purity of 99.5 percent -- a level far higher than the purity of commercial grade acetone. Other universities, such as Stanford, are already planning on-site recycling efforts using Recyclene stills (Harvey Chock, pers. comm.). Several features of Recyclene stills make them superior to the solvent stills currently operated by the College of Chemistry: Recyclene units do not need to be operated under a fume hood, they recycle 10-200 gallons of solvent a day, and the energy costs of running them are only about one-tenth the cost of buying new acetone (Eric Sklar, pers. comm.). Furthermore, Recyclene's stills do not constitute a fire hazard, an issue which has been of some concern in operating stills within the College of Chemistry (Edward Dutto, pers. comm.).

Commercial recycling firms, such as Solvent Services in San Jose, will haul away, distill, and sell spent solvents. Solvent Services does not recycle unless they receive a 500- to 1000-gallon shipment with a 60-percent concentration of a particular solvent (Solvent Services, pers. comm.), so to ensure recycling, EH&S would not only have to meet these concentration requirements, but also have to coordinate its shipments of a specific solvent with shipments of the same solvents from other generators, as UCB probably would not be able to make a 500-gallon shipment on its own. However, since industrial generators often make regular and predictable solvent shipments, this may not be so difficult.

The cost of recycling through Solvent Services is $150-275 per 55-gallon drum, plus a $200 pick-up charge, regardless of the number of drums picked up. Other universities, like Stanford and UC Davis, have found it economical to recycle solvents through commercial recycling firms. UC Davis's EH&S Department, which sends solvents such as paint thinner to commercial recycling firms, estimates its disposal costs to be $4.48 per gallon for recycled solvents, $6.08 for solvents burned for energy recovery, and $10.35 for solvents destructively incinerated (John Seabury, pers. comm.).

Recycling Fluorescent Bulbs: The California Department of Health Services (DOHS) is in the process of formulating a policy regarding the disposal of fluorescent bulbs. The interim policy states that generators may dispose of up to 25 bulbs per day as non-hazardous waste (DOHS, 1987), making the yearly disposal limit per generator in municipal waste stream 9,125 bulbs. UCB's Department of Facilities Management (DOFM) conservatively estimates that they order only 3,000 fluorescent bulbs each year. The roughly comparably-sized UC Davis campus disposes of 150,000 bulbs annually (John Seabury, pers. comm.). There is clearly a discrepancy between these two figures.

A study of UCB's solid waste stream (Gurule, this report) indicates that the campus disposes of about 182 tons per year of hazardous waste in dumpsters, of which 18 percent, or 65,500 lbs., are fluorescent tubes. Taking an average weight per bulb of 10 ounces, Jeff Gurule estimates that over 104,800 of UCB's fluorescent bulbs end up in municipal waste streams each year. While this is a rough estimate, it clearly indicates that UCB disposes of an amount that far exceeds the legal limit.

If fluorescent bulbs are going to be recycled, they must first be crushed. Since mercury vapors are toxic, a special bulb crusher is necessary. Quicksilver Inc., another South San Francisco company, sells a bulb crusher for $8,000. This machine would be operated most efficiently by DOFM since the Department's Janitorial Division changes all the bulbs on campus. Crushed bulbs would be sent to Quicksilver Inc. by a common hauler, because Quicksilver has received an exemption from DOHS allowing fluorescent bulbs to be shipped as a non-hazardous waste. The bulbs would be packed in 55-gallon drums; each drum can hold roughly 800 crushed bulbs. Quicksilver Inc. charges $120 per drum of crushed bulbs it receives, so a shipment of 100,000 bulbs a year would cost $15,000 (Ritchey Vaughn, pers. comm.).

Waste Exchange: EH&S has estimated that as much as 10 percent of the wastes it disposes of are unused chemicals (David Belk, pers. comm.). Normally when EH&S receives unused chemicals from a laboratory, they ask the lab personnel if someone else on campus may be able to use them. On rare occasions EH&S finds someone who wants the chemicals, but usually they must be packed for disposal. Others on campus have also made an effort to redistribute these chemicals. Cindy Keim, a technician working in the Biochemistry stockroom, takes both unopened and opened bottles of chemicals from various labs disposing of them. As a trained technician, she feels she is a good judge of which chemicals are uncontaminated. She distributes these chemicals to various labs on campus, to a chemistry stockroom run by Lamar Willis, and to local junior colleges and high schools. Mr. Willis also collects and redistributes unopened bottles within the College of Chemistry, on an informal basis.

More formal waste exchange systems have been set up at other universities. The University of Illinois' Organic Chemistry Department has set aside a stockroom solely for redistribution of unused, partially used, and synthesized chemicals. A list of chemicals available for redistribution is circulated. Peter Ashbrook, head of that University's Hazardous Waste Management Section, estimates that the Organic Chemistry Department's waste exchange system saves $13,000 each year in avoided purchase costs while spending only $3,000 annually on redistribution.

A campus-wide redistribution system is in operation on the University of Wisconson, Madison Campus. The exchange system is operated by the Waste Management Office of the University, and saves $20,000 dollars a year (Peter Reinhardt, pers. comm.). There is a database inventorying all the chemicals in the redistribution stockroom. When a researcher requests chemicals from this stockroom, the stockroom personnel deliver them to the lab. The University is able to avoid the legal restriction of a 90-day storage limit on hazardous waste by calling its waste exchange center a "surplus chemical stockroom."

EH&S personnel, Cindy Keim, and Lamar Willis all feel that UCB would benefit by having a more formalized waste exchange system. This would primarily involve setting aside storage space, informing labs of this exchange system, collecting chemicals, and publishing an inventory of the chemicals available at this recycling stockroom. Mr. Willis (pers. comm.) also emphasizes the need to ensure that personnel running such a stockroom would be properly trained in identifying and handling chemical compounds.

Discussion

Solvent Recycling: Solvent distillation really entails adapting a recycling technique used widely by industries generating massive quantities of spent solvents to the smaller scale of a research institution. Aside from the problems of collecting enough solvent to warrant a distillation program, solvent purity is also a greater concern among researchers than in industry. For these reasons, acetone is a particularly attractive target for a recycling effort. Not only is it consumed in large amounts on campus, but it is primarily employed in cleaning glassware, a task for which solvent purity is not a major issue. However, certain contaminants would be difficult to distill out of acetone. Thus a necessary part of any collection process would be a program teaching researchers which contaminants make acetone unrecyclable. In addition, a trained chemist would have to operate solvent stills on campus in order to ensure the quality of the recovered acetone. Once a system was set up to recycle acetone, prospects for recycling other solvents could be reviewed.

In order to make a solvent distillation effort economically viable, costs of disposing of acetone legally must be considered. If most of the estimated 1,100 gallons of acetone the College of Chemistry illegally dumps down the drain each year could be collected, perhaps 1,000 gallons of acetone would have to be disposed of. At a price of $505 per 55-gallon drum, the expenses of incinerating of 1,000 gallons of acetone would exceed $9,000. If this same acetone were recycled off-site, this figure could be reduced to about $5,400. If recycling were done on-site, however, money saved in purchasing acetone, which costs $2.50 per gallon (College of Chemistry, 1986), would be approximately $2,500. The main expenses of running a solvent still, on the other hand, would be the one-time cost of the machine itself, the part-time trained technician needed to run it, and energy costs of about $250 for recycling 1,000 gallons. Since acetone purchase and disposal costs are escalating rapidly, a recycling program might very well be a money-saving proposition. However, this would only hold true if UCB did choose to dispose of acetone legally.

Fluorescent Bulb Recycling: A program directed at recycling the mercury from fluorescent bulbs would serve two main purposes. Firstly, it would provide UCB with a safe method for handling a hazardous waste it currently treats as non-hazardous. Secondly, because fluorescent bulbs are a waste generated by all departments at UCB, a recycling program might serve to raise campus awareness of how pervasive the hazardous waste disposal problem is. In constructing a recycling program, the key element is to find out how many bulbs are being thrown away. Data gathered by Jeff Gurule (this report) indicate that UCB far exceeds the legal limit for municipal waste disposal of 9,125 bulbs per year. So if UCB does choose to dispose of the bulbs properly, recycling costs must be considered only in comparison with alternative disposal methods. A crusher would be a necessary expense regardless of how bulbs are disposed of. Landfilling and incineration charges for a 55-gallon drum of bulbs exceed the $120 recycling fee. Moreover, bulbs could only be shipped as non-hazardous waste if sent for recycling, making recycling clearly the most economical method of bulb disposal.

Waste Exchange: Though waste exchange systems have been used on very large scales in European industry, they seem well-adapted to a university setting. Academic labs use many different chemicals in irregular quantities, a situation for which waste-exchange systems are well-suited.

As other universities have shown, an efficiently-operating exchange system can save money and can often be convenient to researchers, who do not have to wait for chemicals to arrive from a manufacturer. However, such a system may be ignored by individuals who do not trust the quality of the surplus chemicals. Not all chemicals will be easily redistributed: the University of Illinois, which has been running its exchange system for almost 30 years, has found that only relatively expensive chemicals are easily "recycled." The details of which chemicals are worth redistributing could be better determined in two ways: by talking with stockroom personnel at the University of Illinois's surplus chemical stockroom and by conducting pertinent representative surveys of labs on the UCB campus. The key obstacles to such a program seem to be space, a scarce commodity on the Berkeley campus, and the awareness and cooperation of researchers necessary to get the system running efficiently. This second problem would best be solved by the publication and distribution of a list of available surplus chemicals, which would require setting up a database of stored surplus chemicals.

Conclusions

This paper has examined only the basic mechanisms and problems associated with starting hazardous waste recycling at UCB. More detailed studies of each specific recycling process would have to be undertaken before the University could implement any of the three recycling options explored here. Nevertheless, this introductory inquiry seems to indicate that hazardous waste recycling is a viable alternative for UCB.

EH&S has also looked into the recycling options discussed here, and is interested in pursuing them further, but sees two main obstacles (David Belk, pers. comm.). Firstly, because EH&S's hazardous waste disposal section operates as a service group to the campus and not as a policing agency, it cannot force the College of Chemistry to dispose of its acetone legally, or DOFM to stop throwing its fluorescent bulbs into municipal garbage dumpsters. Without the cooperation of these (and other) departments, the recycling programs proposed here would be impossible. Secondly, EH&S receives only enough funding to handle the waste it currently processes. Setting up any of the three recycling options discussed here would involve an initial capital outlay and EH&S would need an increased budget to maintain these progressive programs.

Clearly, establishing the necessary prerequisites to begin recycling at UCB -- an increased budget for hazardous waste disposal and greater campus cooperation -- lies beyond the scope of EH&S's power. Effective hazardous waste recycling schemes cannot start until the campus administration gives both its financial and political support to such programs. Moreover, the present shortcomings in hazardous-waste-recycling indicate a need for the administration to begin considering hazardous waste disposal from a more long-term perspective, taking into account increased future disposal costs and, more importantly, UCB's responsibility as an educational institution to engage in environmentally ethical practices.

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