Chapter 8
Waste Minimization Strategies and Chemical Waste Disposal

All laboratory work with chemicals eventually produces chemical waste. It is everyone's legal and moral responsibility to minimize the amount of waste produced and to dispose of chemical waste in a fashion that has the least impact on the environment. Depending on what is contained in the waste, some waste must be professionally incinerated or deposited in designated landfills, while other waste can be neutralized or discharged in normal waste streams.

In 1980 the U.S. Environmental Protection Agency (US EPA) put into effect federal regulations for a hazardous waste management system. These regulations were developed to establish a "cradle to grave" system for the management of hazardous wastes from all sources. In Illinois these regulations are administered by the Illinois Environmental Protection Agency.

The intent of this chapter is to provide schools with information which will help them to minimize the amount of chemical waste that is generated and effectively deal with chemical wastes that are produced.

8.1 Waste Minimization

Waste minimization is any action that reduces the amount and/or toxicity of chemical wastes that must be shipped off-site for disposal as hazardous waste. The US EPA has established a hierarchy of waste minimization approaches:

1. **Source reduction** (most desirable) — includes any activity that reduces or eliminates the generation of chemical waste at the source.
2. **Recycling** — includes using a waste material for another purpose, treating and reusing it in the same process, or reclaiming it for another process.
3. **Treatment** — includes elementary neutralization or another method that is conducted in the laboratory as part of an experimental or analytical procedure.

8.1.1 Interactive Teaching Software and Demonstration Videos

An alternative to handling and disposing hazardous chemicals is to show the reaction using instructional media. For example, if the dangers of performing a thermite reaction in class prevent your students from seeing this demonstration, you could show the reaction on video. Interactive CD-ROM software that can be used in a networking environment is now on the market and is appropriate for high school use. Videotapes and videodisks are also available to demonstrate chemical reactions. Some vendors for courseware and videos are included in the list of reference materials at the end of this chapter.

8.1.2 Chemical Tracking Software

Computer software programs have been developed to assist in the tracking of chemicals from the time of ordering to the time they are consumed or disposed of. Such software can keep track of inventory information, indicate when it's time to order more of a chemical, keep summaries of usage, keep track of where things are located in storage, and provide a variety of other useful tools.

One such program is the CHEMIS (Chemical Health and Environmental Management in Schools) program which has been made available through the State Fire Marshall's office for inclusion in this manual. A copy of the CHEMIS management system disc is included with this manual. Directions for installation and use of the software are found in the CHEMIS manual.

8.1.3 Recycling Chemicals

Whenever and wherever possible, chemicals should be recycled before they become "chemical waste". This can mean using cyclic experiments, where the product of one reaction becomes the starting materials for the next experiment. This can mean using chemicals from another lab when they are no longer needed, or it can mean exchanging or otherwise making chemicals available to other schools. See section 8.1.9 for information on shipping and transporting chemicals.

8.1.4 Substitutions of Non-toxic Substances

Where possible, substitutions should be made to minimize the hazards and disposal costs associated with using a chemical. The following list is an example of substitutions that can be made. The exact substitution will depend on the application. In selecting a substitute, select the chemical that has a higher TLV (threshold limit value) or PEL permissible exposure limit). You should keep in mind that reducing the toxicity by substituting chemicals does not necessarily make the substitute nonhazardous for disposal purposes.

Possible Substitutions for Toxic Chemicals

Toxic Chemicals Relatively Non-toxic Substitutes

Chloroform l,l,l-Trichloroethane
Carbon tetrachloride Tetrachloroethylene
1,4-Dioxane Tetrahydrofuran or 1,2-
Dimethoxyethane
Benzene Cyclohexane or Toluene
Xylene Toluene
2-Butanol n-Butyl alcohol
Lead chromate Copper carbonate
p-Dichlorobenzene p-Nitrotoluene or naphthalene or lauric
acid (for melting point determination)
Potassium Calcium
Dichromate/Sulfuric acid
mixture
Ordinary detergents
Trisodium phosphate Ordinary detergents
Alcoholic potassium
hydroxide
Ordinary detergents

8.1.5 Microscale Experiments

Microscale experiments can be used to reduce the amount of hazardous material required, thereby reducing the hazards encountered when working with the chemicals and reducing the disposal costs. Laboratory manuals and microscale equipment are available through many laboratory supply vendors and publishers. See section 4.1.1 for a discussion of microscale experiments.

8.1.6 Classroom Demonstrations

Another effective way to reduce hazards for students and reduce amounts of waste generated is to perform classroom demonstrations for a variety of more hazardous experiments rather than have each student carry out the experiment. Often this proves to be least hazardous for the student. See section 4.1.2 for safety guidelines for classroom demonstrations.

8.1.7 Model Programs Developing Low Hazard Experiments

A group of graduate students at the University of Illinois at Urbana-Champaign has formed an organization, Encouraging Tomorrow's Chemists (ETC), which has developed a series of experiments that can be used in senior and junior high schools. The primary intent of these hands-on experiments is to "demystify" science. Experiments are one-to-two periods long and currently include the topics of polymers, luminescence, forensics, environmental chemistry, chemistry of life, and imaging chemistry. Since these experiments also serve to reduce the use of hazardous chemicals, most products from the experiments can be discarded in normal waste streams. The address to contact for more information is in the references at the end of this chapter.

The Rend Lake College Videolab/Kitchen Chemistry project was developed through a Dwight D. Eisenhower Mathematics and Science Education Grant administered by the Illinois Board of Higher Education. The module is a unique combination of interactive computer programs and "EPA safe" (i.e., waste may be poured down the drain) hands-on experiments that provides a rather complete and appropriate series of laboratory experiences. This model program reduces hazards, lowers costs, and increases instructional time by reducing set-up and clean-up time. The experiments are especially useful for high schools with limited financial resources and inadequate facilities. The address for more information is in the references at the end of the chapter.

Additional model programs can be considered for future editions of this guidebook submitting them to Gwen Pollock, Illinois State Board of Education, 100 North First Street, Springfield, IL 62777-0001.

8.1.8 Purchasing Chemicals

When purchasing chemicals, it is important to consider a variety of things beyond the immediate need for the chemical. CHEMIS has suggested asking the following six questions before purchasing a chemical:

1. Can proper storage be provided for this chemical?
2. Are facilities appropriate for the use of this chemical?
3. Will this chemical or end product need to be disposed of as hazardous waste?
4. Is adequate personal protective equipment available for the use of the product?
5. Have personnel who will handle and use this chemical been trained and are they aware of the hazards?
6. Is the quantity being ordered appropriate for the anticipated use? Asking for an MSDS from the company before purchasing the chemical may help to provide this information.

When ordering any chemical, **do not order a supply for greater than two years of use**. Remember to maintain a complete chemical inventory.

8.1.8.1 Container Sizes

Historically, there has been significant incentive to buy larger sizes of chemical containers because the unit cost of chemicals is generally much less. This justification may no longer be valid if one takes into account potential risks and disposal costs. Some reasons why chemicals should be purchased in small containers include:

1. Extended storage of unused chemicals increases the likelihood of breakage or leaks. Larger bottles tend to break more readily than smaller bottles, creating greater risks and costs associated with cleaning up spills. Accidents also increase negative publicity and legal liability.

2. Disposal costs are continuously escalating. As experiments and teachers change, stored chemicals may no longer be needed.
3. Smaller packages are emptied faster, which lessens the likelihood of decomposition or having chemicals go beyond their expiration dates.
4. Storage of large quantities results in higher costs, such as additional stockroom space and engineering measures to prevent and control fires and to increase ventilation.
5. Purchase of large quantities means that smaller “transfer” containers are required. This increases the likelihood that the small containers will be labeled improperly or that labels will be lost. According to the American Chemical Society's Task Force on Laboratory Waste Management, the cost of analysis of a small amount of an unknown can exceed $1000. They also suggest that disposal costs can easily surpass the purchase price, especially for wastes that are difficult to dispose of, such as those containing toxic metals or dioxin.

8.1.9 Shipping and Transporting Chemicals

If chemical exchanges are made between schools on public highways, it is important that all Department of Transportation guidelines be followed. The Illinois Department of Transportation Haz Mat Compliance Unit has provided a clarification of 8-7
the Hazardous Materials Regulations (49 CFR 171.8) of the United States Department of Transportation (US DOT).

The US DOT has indicated in a recent interpretation that “person” is defined in Section 171.8 as any legal entity that handles, transports, or offers hazardous materials for transport in “commerce” or “in the furtherance of commerce”. Hazardous materials handled by government vehicles are not generally considered to be handled or transported “in commerce” or “in the furtherance of commerce” under that definition and are therefore not subject to the regulation. Based on this interpretation, the Illinois Department of Transportation does not consider elementary and secondary schools and their employees who handle or transport hazardous materials in school owned and operated vehicles, for school programs, to be operating “in commerce” or “in the furtherance of commerce” and therefore are not regulated. The interpretation issued by US DOT does state however, that governmental agencies are regulated when offering hazardous materials for transportation to a carrier operating “in commerce” or “in the furtherance of commerce”. Therefore, when elementary or secondary school employees offer hazardous materials to a carrier operating “in commerce”, the actions of those employees are regulated under the hazardous materials regulations. For example, if school employees were to offer waste chemicals to a carrier operating “in commerce” for transportation to a disposal facility, those employees would have to be properly trained on how to classify, describe, package, mark, label and offer hazardous materials for transportation.

8.1.10 Twenty-five Ideas to Help Reduce Your Hazardous Waste

The Chemical Waste Management section of the Division of Environmental Health and Safety at the University of Illinois at Urbana-Champaign (UIUC) has developed a list of ways to reduce hazardous waste in university research and teaching labs. Following are excerpts adapted for high school chemistry laboratories:
1. Evaluate experiments and demonstrations to see if less hazardous or nonhazardous reagents could be used.
2. Purchase chemicals in smallest quantities needed.

3. Date chemical containers when received so that older ones will be used first.
4. If possible, establish an area for central storage of chemicals.
5. Establish an area for chemical waste.
6. Write a waste management/reduction policy.
7. Inventory chemicals at least once a year.
8. Centralize purchasing of chemicals through one person in the school.
9. Include waste reduction as part of student training.
10. Use manuals such as the American Chemical Society (ACS) "Less is Better" or "ACS Waste Management for Lab Personnel" as part of your training. Label all chemical containers as to their content so that they don't become "unknowns".
11. Develop procedures to prevent and/or contain chemical spills: purchase or make spill clean-up kits, use secondary containment in areas where spills are likely.
12. Segregate your wastes to reduce volume and costs for disposal:

- Keep recyclable waste/excess chemicals separate from nonrecyclables.
- Keep nonhazardous chemical wastes separate from hazardous waste.
- Keep organic wastes separate from metal-containing or inorganic wastes.
- Keep halogenated solvents separate from nonhalogenated solvents.
- Keep highly toxic wastes (cyanides, etc.) separated from above.

13. Use the least-hazardous cleaning method for glassware. Use detergents such as Alconox, Micro, or Pierce RBS-35 on dirty equipment rather than/or before using KOH/ethanol bath, acid bath, or No Chromix.
14. Substitute red liquid (spirit-filled), bimetal, digital, or thermocouple thermometers for mercury thermometers where possible.
15. Avoid the use of reagents containing barium, arsenic, cadmium, chromium, lead, mercury, selenium, and silver.
16. Consider the quantity and type of waste produced when purchasing reagents.
17. Purchase equipment that enables the use of procedures that produce less waste.
18. Review your procedures regularly (e.g., annually) to see if quantities of chemicals and/or waste could be reduced.
19. Look into the possibility of including detoxification and/or waste neutralization steps in laboratory experiments.
20. Scale down experiments producing hazardous waste wherever possible.
21. Use preweighed or premeasured reagent packets where waste is high.
22. Encourage orderly and tidy behavior in the lab.
23. Be wary of chemical "gifts" from outside the school. Chemical gifts can very easily become your "hazardous waste."
24. Use demonstrations or video presentations to replace experiments that produce large amounts of hazardous waste.

8.2 Laboratory Waste Disposal

It is inevitable that some quantity of chemical waste will be generated as a result of teaching chemistry. Due to the problems, costs, and potential hazards associated with this chemical waste, it is strongly recommended to do everything possible to minimize the amount of waste generated (section 8.1). Chemical waste can be either hazardous or nonhazardous, with each type requiring different handling and disposal.

8.2.1 Hazardous Waste Defined

Wastes are classified by the EPA as hazardous if they are specifically listed in 35

IAC subtitle G part 721 subpart b or meet at least one of the following characteristics:

1. **Ignitable** — has a flash point of <140° F, is an oxidizer, or is an ignitable compressed gas;
2. **Corrosive** — has a pH ≤ 2.0 or a pH ≥ 12.5;
3. **Reactive** — is reactive with air or water, is explosive, or is a cyanide or sulfide;
4. **Toxic** — has certain levels of certain metals, solvents, or pesticides greater than prescribed limits. Non-hazardous wastes are all other chemical substances that are not covered under of these definitions.

8.2.2 Disposal Options

Small quantities of nonhazardous wastes can be disposed of in an approved special waste landfill, dissolved in water and flushed down the sanitary sewer, or handled as hazardous waste. Large quantities of nonhazardous chemicals may need to be handled by a professional contractor. Take care to avoid the appearance of a problem even though one may not actually exist. Examples of these problems would be throwing away vinegar and baking soda in the same waste container. If they mix, the result is a harmless but very visible reaction. Another common occurrence is the once-a-year storeroom cleanup. This activity generates large quantities of brown bottles with mysterious (to untrained personnel) powders in the trash dumpster. To those with chemophobia, the powders appear toxic. Properly disposing of even small quantities of hazardous waste becomes a more involved and costlier process. All hazardous wastes, except for neutralizable acids and bases and water soluble alcohols, must be handled by professional disposal contractors. The usual procedure involves the contractor placing a number of bottles in a pail or drum to create what is called a lab-pack. This lab-pack is then incinerated, buried in a hazardous waste permitted landfill, or sent for specialized treatment. The treatment method can easily cost several thousand dollars.

8.2. 3 Neutralization of Strong Acids and Bases

Neutralization is the most efficient and least costly way of managing waste acids and bases. The following procedure comes from the UIUC Waste Minimization Bulletin No. 10.3 As always, do not perform a procedure that you do not feel comfortable doing. After neutralization, waste liquids can be disposed of in a sanitary sewer.

Procedures for Neutralization of Strong Acids and Bases

A. Personal Protection and Equipment

Carry out neutralizations in a well-ventilated fume hood. Use the sash or a safety shield for protection against vigorous reactions. Wear an apron, splash-proof goggles, or a full-face shield and nitrile gloves. Long gloves or gauntlets are also recommended. A 5-gallon polyethylene bucket is recommended for neutralizing 1-10 liters. A large container is needed in acid neutralization for addition of ice and base and for stirring the reaction safely.

B. Solutions That Should Not Be Neutralized

The solution you plan to neutralize should not contain heavy metals such as arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver. Wastes containing high levels of other metals may be of concern as well. Your local sanitary district can tell you if these wastes can be neutralized and sewered. Acids that are very reactive with water should not be neutralized unless you are expert in handling and using these acids. These include: acid anhydrides and chlorides; chlorosulfonic acid, fuming nitric and sulfuric acids; liquid halides of boron, silicon, tin, titanium, and vanadium; and liquid halides and oxyhalides of phosphorus, selenium, and sulfur. Hydrofluoric acid is also very dangerous and should not be neutralized unless you are an expert handling it and know what you are doing.

C. Procedures — Neutralization of strong bases Bases that may be neutralized include: solutions of potassium and sodium hydroxides, alcoholic sodium or potassium hydroxide cleaning solutions, ammonium hydroxide and ammonia solutions.

1. Dilute the base to a 5% (by weight) concentration or less.
2. Slowly add 6 N hydrochloric acid or other acid.
3. Monitor pH changes with pH meter or pH paper. (Note: Liquid indicators can oxidize rapidly in basic solutions and give false color change).
4. When pH is between 6 and 10, solution can be washed down sanitary sewer with 20 parts water.

D. PROCEDURES - Neutralization of strong acids

1. Prepare a 6 N solution of sodium hydroxide (240 grams/liter of water) or potassium hydroxide (336 grams/liter of water).
2. One liter of 6 N base can neutralize:

Acid	**Quantity in ml**	**Acid**	**Quantity in ml**
Acetic acid (glacial)	342	Nitric acid (70%)	378
Formic acid (88%)	264	Perchloric acid (70%)	516
Hydrochloric acid (37%)	504	Phosphoric acid (85%)	414
Hydrobromic acid (48%)	720	Sulfuric acid (96%)	166
Hydriodic acid (47%)	1080	Trichloroacetic acid (20% solution)	4902

3. Dilute the acid to a 5% (by weight) concentration or less (add acid to water, **not** water to acid). Use ice as necessary to cool the solution. Limit the solution to a maximum of 10 liters. Acids that may generate heat upon neutralization are phosphoric and sulfuric acids.
4. Neutralize with 6 N sodium hydroxide or potassium hydroxide, adding it slowly.
5. Monitor pH with pH paper, a pH meter, or a suitable indicator.
6. When pH is between 6 and 10, wash solution down the sanitary sewer using 20 parts water.

8.2.4 Disposing of Laboratory Waste Using the Sanitary Sewer System [1]

It is important to realize that sewage disposal plants vary by location in capability and the type of operation they carry out. The information presented here is a summary of what is generally accepted in present literature. As disposal plants vary, so will their ability and willingness to accept various laboratory or other wastes in the wastewater stream. Laboratory wastes should never be dumped into a drain that leads to a septic system. Modest quantities of many common laboratory chemicals can be disposed of through the sanitary sewer system if local regulations and plant operator approve. Check with your local treatment plant operator to find out exactly what is acceptable and what is not because treatment facilities also have varying regulations governing their activities. The inquiry should include the specific disposal precautions that the school proposes to take and the applicable material safety data sheet (MSDS). If possible, verify acceptable wastes in writing. Contacting and securing written permission by the local officials does not exempt the school from any local, state, and/or USEPA enforcement if the waste discharged causes a problem in the collection system or at the waste water treatment plant.

The following precautions should always be used:

- Use a drain that empties into a wastewater treatment facility, not a storm drain, combination (sanitary and storm) sewer, or other drain that flows untreated into surface water. It is likely that such drainage directly into surface waters would be in violation of the Clean Water Act (CWA) or Storm Water Regulations.

- Limit quantities of chemicals to a few hundred grams or milliliters. Do not use drains for large quantities.

- Dispose of only soluble wastes and dilute at least 1000-fold with water at the drain.

- All acids and bases should be neutralized before disposal in the sewer system. Check pH level before disposal. Note: some regulatory agencies consider neutralization as treatment and require obtaining separate, most of which are very time consuming and expensive.

- Remember: **Some** chemicals may be disposed of by using the sewer system, but **most** may not.

8.3 Resources

ETC Program
University of Illinois at Urbana-Champaign
Box 90-5, Roger Adams Laboratory
S. Mathews
Urbana, IL 61801
Rend Lake College Videolab/Kitchen Chemistry Project
Dr. John Fisher
Rend Lake Community College
Ina, IL 62846
437-5321
Hazardous Waste Resource and Information Center
Woodfield Drive
Savoy, IL 61874
Illinois Department of Transportation
Terrence Moore
HAZ MAT Compliance Unit
Division of Traffic Safety
Executive Park Drive
Springfield, IL 62794-9212
Illinois EPA

Emergency Response Unit
Churchill Road
Springfield, IL 62706
8-14
US EPA
Region 5
Waste Management Division
S. Dearborn Street
Chicago, IL 60604
Office of the State Fire Marshall
Stevenson Dr.
Springfield, IL 62703-4259
Some Vendors of Instruction Software and Videos
American Chemical Society
1155 16th. St. N.W.
Washington, D.C. 20036
800-227-5558
Falcon Software, Inc.
Box 200
Wentworth, NH 03282
603-764-5788
Journal of Chemical Education Software
Department of Chemistry
1101 University Avenue
University of Wisconsin-Madison
Madison, WI 53706-1396
608-262-1483
Trinity Software
P. O. Box 960 Campton, NH 03223
1-800-352-1282

8.4 References

1. CHEMIS. 1994. *Chemical Health & Environmental Management in Schools-Systems Management Manual*. Independence, MO: Pan-Educational Institute
2. Task Force on Laboratory Waste Management. 1993. *Less is Better*, p. 5. Washington, D.C.: American Chemical Society
3. University of Illinois at Urbana-Champaign Division of Environmental Health and Safety. 1995. Neutralization of Strong Acids and Bases. *Waste Minimization Bulletin #10*