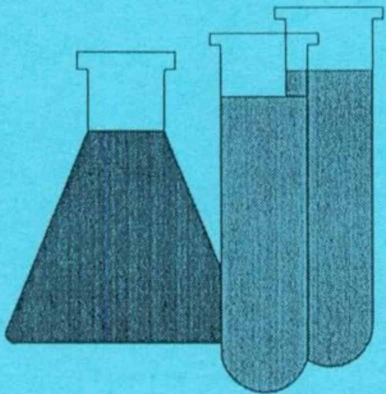
Laboratory Waste Minimization and Pollution Prevention

A Guide for Teachers



Battelle

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A Guide for Teachers

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About Battelle

This handbook was prepared by staff at Pacific Northwest Laboratories and the Battelle Seattle Research Center. The Pacific Northwest Laboratories are operated by Battelle for the U.S. Department of Energy (DOE). Battelle, with a staff of over 8,000 professionals, has delivered technology-based service to industrial and government clients for over 65 years. Battelle's major mission areas are commercial and industrial technology, health, national security, transportation, and the environment.

As part of its environmental mission, Battelle seeks to promote the use of pollution prevention ("P2") technologies and practices. Examples of Battelle's efforts in the area of pollution prevention and waste minimization include:

- developing guidance for the U.S. Environmental Protection Agency on conducting waste minimization audits (the EPA "purple guide")
- developing and implementing P2 technologies in a wide variety of manufacturing applications—such as the elimination of ozone-depleting substances
- assisting government and industrial clients in identifying, prioritizing, and reducing hazardous and other waste streams
- developing innovative pollution prevention tools such as Life Cycle Assessment and Design for Environment
- examining organizational and management issues affecting the successful implementation of P2.

If you have specific comments or questions about this handbook or Battelle, please contact Elizabeth Flores at (509) 372-4230.

If you would like to learn more about Battelle, and you have access to the Internet, check our home pages: Battelle (http://www.battelle.org), PNL (http://www.pnl.gov:2080), or the Battelle Seattle Research Center (http://www.seattle.battelle.org).

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1 Introduction

This guide explains how you can minimize the hazardous wastes and other chemical pollution generated by experiments that are performed in classroom laboratories. It is intended for middle school, high school, and college science teachers.

Specifically, this guide will help you

- Generate less waste and pollution *and* save money by purchasing chemicals effectively.
- Substitute safer chemicals for hazardous chemicals.
- Deal with a large inventory of mislabeled or unlabeled chemicals that were left by another teacher.
- Communicate the importance of waste minimization to school administrators.
- Recycle chemicals.
- Teach students environmental responsibility as you teach them to perform experiments.

This guide deals primarily with chemicals that will be used in a chemistry or biology laboratory in an educational institution. It does not deal with radioactive materials.

The guidance presented is just that—guidance. Weigh it against other factors and always follow your good judgment; prudent safety practices; federal, state, and local laws and regulations; and school policies.

Because this guide is intended for teachers ranging from middle school to college, some of the guidelines we present may not apply to you. For example, guidance to substitute cyclohexane for benzene would be irrelevant to a middle school science teacher, whose students would never use a substance as hazardous as benzene. Similarly, a high school teacher might not have access to the resources needed to obtain the equipment necessary to do microscale experiments. If a guideline doesn't apply to you, it may give you

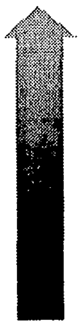
Some of the references in Chapter 15 will help you identify these regulations.

The waste management hierarchy

There are a variety of methods to deal with the problem of hazardous wastes.

The Waste Management Hierarchy

Most desirable



Reduce waste production at the source.

Recover and reuse wastes on-site (i.e., recycling).

Recycle off-site.

Treat wastes to reduce volume or toxicity.

Dispose of wastes in a manner that protects air, water quality, land quality, and human health and safety.

Least desirable

The waste management hierarchy above shows methods of dealing with hazardous waste, in order of preference. The most preferable option on the hierarchy is to reduce the amount of waste that is produced in the first place. This approach—known as source reduction—means that no one has to deal with the waste at all. This is the cornerstone of pollution prevention.

Unfortunately, not all waste can be eliminated, and the waste that is generated must be dealt with. The second best option for managing this waste includes recycling, refining, or recovering the waste for reuse so that new raw materials are not required and so that waste pollutants never reach the land (e.g., a landfill), the water, or the atmosphere, and resources are conserved.

If that is not possible, the next best option would be to treat the waste to reduce its toxicity and its potential for harming the environment.

The least preferred management method for hazardous wastes (and non-hazardous wastes) is disposal by landfilling or incineration with proper disposal of the residual ash.

While each of these options may be necessary for managing waste at certain times, it is in our best interests to always try to "move up the management hierarchy" with the wastes we generate. At the top of the hierarchy, source reduction should be the corner-stone of our efforts. It is the emphasis of this guide.

3 Why are Waste Minimization and Pollution Prevention Important?

There are a number of reasons.

Waste minimization and pollution prevention are environmentally responsible. By reducing wastes at the source, you are taking the most effective step towards eliminating wastes that would otherwise be released to the environment. Schools are highly visible members of the community, and waste minimization provides the opportunity to set an example for the community, even if a school generates relatively little waste.

> " Waste minimization teaches environmental responsibility.

Practicing waste minimization and pollution prevention in schools *teach* environmental responsibility. By emphasizing the importance of these approaches to your students, you can help instill habits that will be of value the rest of their lives—in the laboratory, on the job, and at home.

Waste minimization and pollution prevention encourage safety in the laboratory. Hazardous wastes can be hazardous to students and teachers, as well as to the environment. If you reduce the quantity of hazardous substances they handle, you reduce the hazard.

Waste minimization and pollution prevention save money. One effective waste minimization practice is to reduce the quantity of chemicals purchased, which in turn reduces the amount of money that is tied up in chemical inventory. Reducing chemical use will also reduce disposal costs, which can run from $4 to $22 per gallon.

Finally, waste minimization and pollution prevention help ensure schools meet legal requirements. There are federal, state, and even local laws that govern waste disposal. Many schools may be violating some of these laws right now. The best way to comply with these laws is to not generate the waste in the first place.

So how do you minimize waste? Beginning with the next chapter, we'll present some specific suggestions.

Organization of the Following Chapters

We've organized the rest of this guide to reflect the progression of chemicals through the laboratory:

We start out by covering waste minimization techniques you can implement as you buy and store chemicals (Chapters 4, 5, and 6). We emphasize the value of such actions as purchasing smaller quantities and implementing careful inventory controls.

We then turn to techniques you can consider during the planning and running of experiments (Chapters 7, 8, 9 and 10). These include such changes as moving to microscale experimentation, substituting less hazardous for more hazardous compounds, or even using computer simulation in place of wet chemistry where appropriate.

Next, we cover techniques you can apply for the reuse, recycling, or in-laboratory treatment of wastes (Chapters 11, 12, 13). Here the focus is on how to minimize the amount of waste ultimately being disposed by the laboratory.

As a final topic, we cover some of the places you can turn to for support, funding, and more information on waste minimization (Chapters 14 and 15).

At the end of the guidance we have included a sample Waste Minimization Checklist that you might find helpful as you start to implement your program. This checklist summarizes the ideas presented throughout the manual.

4 Purchasing Chemicals

Effective waste minimization begins with effective purchasing decisions. The idea is to buy only what you need, because if you don't buy it, you don't have to get rid of it.

The American Chemical Society estimates that unused chemicals can constitute up to 40% of the wastes generated by a lab. In many schools, unused chemicals have not made it into the waste stream—yet. These schools have an inventory of unused chemicals left over by former teachers or researchers. These chemicals can be a problem for everyone. They may be useless (or even unstable) because their shelf life has expired. Containers may be in poor condition. They may be poorly labeled, illegally labeled, or unlabeled. Unused chemicals can present a safety hazard in the lab and are likely to be difficult and expensive to dispose of.

Chapter 6 will present some specific recommendations for dealing with these inventories. This chapter will tell you what you can do to prevent these inventories from accumulating—preventing damage to the environment, your budget, and your relationship with your successor.

The myth of buying in bulk

All teachers estimate the quantity of a chemical that they will need before purchasing that chemical. Problems arise when these estimates are inaccurate. The simplest way to increase the accuracy of an estimate is to shorten the time horizon; in other words, if you estimate the quantity of a chemical that you will need for a single experiment, that estimate is likely to be more accurate than an estimate of how much you will need for an entire year. If you buy smaller quantities more often, your inventory should shrink.

The problem, many believe, is that it is cheaper to buy chemicals in bulk. When you buy in bulk, you spend less time placing orders, you worry less about shipments arriving on time, and many chemical suppliers will give discounts when a large quantity is purchased.

An important fact to consider, however, is that the cost savings associated with buying in bulk are frequently offset by the costs of disposing of the unused chemicals. The following table presents an example.

The Effect of Disposal Costs

	Package Size	
If 1000 mL are used...	**500 mL**	**2500 mL**
Unit cost	6.2¢/mL	4.2¢/mL
Purchase cost	$62.00	$104.00
Disposal cost	0.00	45.34
Total cost	$62.00	$149.34
Actual unit cost	6.2¢/mL	15.0¢/mL
If 1677 mL are used...	**500 mL**	**2500 mL**
Unit cost	6.2¢/mL	4.2¢/mL
Purchase cost	$124.00	$104.00
Disposal cost	13.08	45.34
Total cost	137.08	149.34
Actual unit cost	8.2¢/mL	8.9¢/mL

In this example, even though the 2500-mL size costs 37% less than the 500-mL size to purchase, the larger size can cost up to about 250% *more* to use once disposal costs are factored in.

Other purchasing strategies

In addition to buying chemicals in smaller amounts, there are other purchasing strategies that can reduce the amount of chemical waste generated.

> “ Find a supplier who can deliver small amounts of chemicals on short notice.

- Select a chemical supplier who will support waste minimization efforts. Find a supplier who can deliver small amounts of chemicals on short notice and who will accept unopened chemicals that are returned.

- Standardize chemical purchases. If all (or most) experiments are designed to use chemicals from an approved list, then another teacher may be able to use your surplus chemicals.
- Consider a centralized purchasing program. If one person does all the purchasing, a laboratory may be able to take advantage of bulk pricing because the purchaser will be buying for more experiments at once.
- If a centralized purchasing program is not feasible at your school, consider passing all orders by one person. This person will be aware of the "big picture" and may be able to point out purchases that can be consolidated.
- It may help to create an "Authorized Use List" of those chemicals that can be purchased in the school. This can serve to steer people towards safer, more environmentally friendly chemicals.

5 Managing Chemical Inventories

Managing chemical inventories effectively can prevent many of the ills that plague environmental managers: unknown chemicals, excessive inventory stocks, and poor use of materials. By managing chemical inventories in a few simple but effective ways, you can avoid many of these problems.

Label chemicals properly

Proper labeling is a simple and powerful way to reduce many of the environmental hazards and costs associated with chemicals used in the laboratory. Since chemistry teachers and students are responsible for producing chemicals wastes, they should shoulder the responsibility for identifying the wastes. Mixing unknown or improperly identified wastes can produce dangerous reactions; people have been injured and killed at waste treatment facilities because wastes were poorly identified and packaged.

Consider also the costs of mislabeled or unidentified chemicals on your shelf: the cost of analyzing a chemical prior to disposal can exceed $1,000, by one estimate, many times the original cost of the product. Properly labeling containers also decreases the risk of accidents and injuries, and aids in complying with regulatory requirements such as hazard communication to the local fire department.

Some recommendations for labeling are:

- Establish a policy that requires identifying all chemical containers—including waste containers—and specifying a responsible party.
- Adopt a standard labeling procedure for chemicals and wastes.
- Use labels that are colorfast and permanent.

6 Dealing with an Existing Inventory of Unwanted Chemicals

If you have inherited a cabinet full of poorly labeled or even unlabeled chemicals from a previous teacher, you are not alone. Many teachers are left with stockpiled chemicals and don't know how to deal with them in a manner that does not present a danger to the environment—or even to themselves or their students.

Old inventories are a common problem. In 1986, a survey was conducted of over 100 secondary schools in Massachusetts. These schools reported that they had 8700 pounds and 500 gallons of unwanted chemicals. Forty-eight percent of the respondents said that chemicals had never been removed from their inventory. A survey of Illinois schools revealed similar problems.

These inventories tend to sit around because it is too much trouble to dispose of them properly. However, the truth is that these inventories are a huge liability—an accident waiting to happen. Dealing with an exposure to a student, teacher, or staff member will be a lot more trouble than safely disposing of the inventory.

Getting help

The first step in dealing with an unwanted inventory is to realize that stockpiled chemicals are not just your problem—they're the school district's problem and even the city, county, or state's problem. The district and local and regional government have an obligation to help and you will need their help to dispose of the stockpile safely.

For example, in Illinois, the state embarked on an ambitious program to assist schools in getting rid of unwanted chemicals. In the summer of 1987, the Emergency Response Unit of the Illinois Environmental Protection Agency oversaw an effort to remove 27,238 pounds of unwanted chemicals from secondary schools. The effort was funded with state spill cleanup funds.

7 Conducting Experiments

Waste minimization in the laboratory doesn't necessarily require major changes in the way you run experiments. Some basic efforts to be more efficient and careful with experimental procedures can substantially reduce the amount of waste generated.

Teach—and practice—resource-efficient procedures

A starting point for waste minimization is being efficient in your use of resources. If you as a teacher place emphasis on being sparing with chemical usage or use of other resources (such as water or electricity), then students will be more likely to pay attention to these resources as well. Getting students to think about the environmental consequences of their laboratory activities makes sense in any experiment. Some suggestions for teaching resource-efficient procedures including:

- Have students use solvents and other hazardous materials sparingly.
- Monitor experimental reactions closely and add additional chemicals only as necessary.
- Emphasize water conservation by reducing rinse times where possible.
- Be alert for opportunities to save electricity. For example, don't leave equipment running when it's not being used.

Set up experiments with waste minimization in mind

In addition to being just plain careful about chemical use, you can take a number of steps in the design and set up of experiments that will help to minimize waste. Chapter 9 will cover in detail the option of scaling down the size of experiments. In addition, some other steps you can take include:

- Pre-weigh chemicals for students. This will take more time on your part, but it will also make lab time more productive for the students.
- Have students work in teams. For example, pairing students can cut the number of chemicals that will be used in half. Pairing also teaches students to work together.
- Alternatively, you may want to demonstrate some experiments yourself, rather than having the whole class perform them.
- Set up a procedure to use spent or recovered solvents for an initial rinse, and save fresh solvents for use in the final rinse only.

Where feasible, include a step as part of the experiment that destroys or inactivates any hazardous products. Chapter 14 will cover "treatment" of hazardous waste materials in more detail. Certain hazardous chemicals such as acids and bases can be easily neutralized as a part of the experiment.

Encourage students to research waste minimization

Finally, a good way to get students thinking about waste minimization as they run experiments is to have them actually research waste minimization techniques. You might think of including an experiment in your curriculum that actually gets the students to identify ways to minimize use of hazardous chemicals or generation of hazardous byproducts.

8 Scaling Down Experiments

Typically, educational experiments are designed at a macroscale level, with little thought about waste minimization. Most macroscale experiments can be easily scaled down and still achieve the same level of analytical rigor. Experimental quantities can be scaled down by about 50% with little effort or cost, or scaled down to 1/100th to 1/1000th of the original quantities using glassware and experiments designed for microexperimentation. The result—less waste, less student exposure, and fewer chemical purchases.

In upper-level chemistry courses, microscaling complements the use of analytical equipment such as chromatographs, spectrophotometers, nuclear magnetic resonance systems, etc. These systems require extremely small sample quantities for analysis.

Reduced scale chemistry

If you cannot convert to true microscale chemistry, try decreasing experimental quantities by a third or half. A 50% reduction in quantities can usually be achieved with conventional glassware. Such scale reductions may require a few trial runs to ensure desired experimental results—a good exercise for students who volunteer for extra credit lab work. (Caution: Instructor supervision is important!)

Microscale chemistry

Microscale chemistry techniques and equipment can reduce chemical use by as many as three orders of magnitude. Efforts at developing classroom micro experiments for general, organic, inorganic, and physical chemistry courses have been and continue to be successful. Several student and instructor textbooks have been published. Some recommended textbooks are listed in Chapter 15. Two of these books (Ehrenkranz & Mauch, 1993, and Waterman & Thompson, 1993) are specifically intended for high school chemistry classes.

Micro techniques are also being explored and developed in radioactive chemistry and radiochemistry. Most microscale techniques can easily be mastered by beginning students, with proper instruction.

As an example, conventional experiments with solids use 10- to 50-gram amounts, while microscale experiments can use as little as 25–100 milligrams (mg). Similarly, experiments with liquids can be cut from 25–100 milliliters (mL) to 100–200 microliters (μL). Highly accurate density and specific gravity determinations can be achieved using less than 1 mL of liquid and a micropipette, rather than the conventional larger volumetric flask method, requiring up to 30 mL of the solution.

An example microscale experiment: Redox Titration of Manganese

Using a graduated or volumetric pipette, place 1.00 (±0.01) mL of 0.0100M $KMnO_4$ solution into each of three 10-mL flasks. Label as A, B, and C.

Acid Solution Titration. Add 1.0 mL of 1M H_2SO_4 to flask A. Charge a microburet with 0.0200M $NaHSO_3$ solution and slowly titrate the permanganate solution drop by drop until the purple color of the solution disappears. Record the volume of $NaHSO_3$ added.

Neutral Solution Titration. Recharge the microburet with 0.0200M $NaHSO_3$ solution. Record initial volume and titrate the $KMnO_4$ solution in flask B. The purple color of permanganate will change to a brown suspension of MnO_2 at the endpoint. Record the final volume.

Basic Solution Titration. Add 1.0 mL of 1M NaOH to the permanganate solution in flask C. Recharge the microburet with $NaHSO_3$ solution. Record initial volume. Titrate to dark green-colored endpoint of MnO_4^{2-} .

The remainder of the experimental calculations and exercises are provided in the textbook.

(Taken from Szafran, et al., 1993 p. 270)

Implementing microscale

An inexpensive way to achieve an initial level of microscale would be to use flexible, small diameter polyethylene tubing instead of bent glass tubing to transfer gases, using micro pipettes, microburets, and Hirsch filtration funnels rather than the traditional larger size equivalents. (Note: Some of the plasticware may not be suitable for organics.)

To fully retrofit a conventional chemistry lab to microscale, some investment is necessary. Full microscale glassware kits cost up to $110 to $150 (advanced levels) per student (1994 prices). Analytical microscale equipment also adds to the initial cost. Typically, one piece of equipment (e.g., one electronic digital balance or one capillary melting point apparatus) suffices for 15 students.

These costs are typically recovered in nine months to three years (depending on the size and scope of the program). Chapter 4 provides possible strategies for acquiring funding or equipment to convert to microscale chemistry.

" The costs are typically recovered in nine months to three years.

The National Microscale Chemistry Center (NMC^2) at Merrimack College in North Andover, Massachusetts, offers free one-week courses in microscale chemistry to educational instructors. Contact the NMC^2 at (508) 837-5137 or send e-mail to zszafran@merrimack.edu for more information. Many other colleges are practicing or are converting to microscale experimentation in their laboratories and may offer training or auditing of courses using microscale.

Microscale equipment

Microscale equipment includes (but is not limited to) 96-count well-plates, plastic and glass micro pipettes, microburets, automatic/digital delivery pipettes, microcentrifuge tubes, syringes, glass or plastic inserts to displace liquid volumes in vials and test tubes, and full glassware kits. Analytical equipment may be necessary for performing certain introductory level experiments, and is important for upper-level courses. Analytical microscale equipment includes (but not limited to) an electronic digital balance, capillary melting point apparatus, automatic delivery pipettes and/or syringes, a magnetic stirring hot plate and sand melting baths, and microscale magnetic stirrers. Typically, one of each piece of equipment will suffice for 15 students. New suppliers are continually entering this growing market.

> “The only wastes are small, inexpensive capillary tubes and the 1 mg of product.

Capillary melting point apparatus eliminates the hazards and mess of the traditional oil bath method and determines accurate melting point ranges using only about 1 mg of the sample. A small modification of the process allows determination of boiling points as well. Observation through a magnifying lens allows the student to view the exact temperature at which melting and boiling start. Equipment operation and maintenance are simple and equipment is very durable. The only wastes are small, inexpensive capillary tubes and 1 mg of product.

The balance should be a single-pan electronic balance with digital readout, automatic taring, and accuracy to .01, .001, or .0001 gram (depending on the allowable level of error and minimal sample mass used). Automatic delivery pipettes are available in digital or manual micrometer volume settings, and can deliver volumes at high accuracy in varying volume ranges. One delivery pipette with a range of 0-100 μL and one with a range of 100-1000 μL should suffice for each 15 students. This eliminates inaccuracies, wastes, and dirty glassware common with other measuring methods. Not all wastes are eliminated with the delivery pipettes, since the small plastic tips must be changed with each measurement of a different liquid. Syringes may also be useful in measuring microscale quantities.

Determining magnetic moments from measurements of magnetic susceptibility of transition metals can be done with very small quantities of product using magnetic balances such as the Evans balance developed by D. F. Evans of Imperial College, or with nuclear magnetic resonance (NMR). These replace traditional methods and require 50 mg or less of sample product.

9 Substituting Materials

Substitution of hazardous chemicals in the laboratories with nonhazardous (or at least less-hazardous) chemicals is an important source reduction strategy. If you use nonhazardous chemicals in place of hazardous chemicals, you've gone a long way towards avoiding a hazardous waste problem. Substitution can sometimes be done in conjunction with scaling down quantities used in experiments (see Chapter 8), giving you a double savings. Both substitution and scaling down experiments should be considered before such options as reuse, recycling, or treatment. (Remember that, according to the waste management hierarchy, source reduction is always preferable to recycling, treatment, or disposal.)

Substitution of hazardous chemicals with non- or less-hazardous chemicals has been achieved by a number of secondary schools, as well as some high schools and introductory college chemistry courses. These schools have created laboratory curricula that rely on chemicals and compounds that can be purchased at the local grocery store, rather than from a chemical supplier. The following table includes some of the possible substitutes for hazardous chemicals.

Possible substitutes for hazardous chemicals

Procedure	Hazardous Chemical	Substitute
Glassware cleaning	Chromic-sulfuric acid solutions Alcoholic potassium hydroxide	laboratory detergents, enzymatic cleaners, aqueous solvents
Density determination	methanol solution	sugar water
Organic synthesis	chromate ion ethyl ether	hypochlorite ion methyl t-butyl ether
Qualitative test for heavy metals	sulfide ion	hydroxide ion
Molecular weight determination by freezing point lowering methods	benzene	cyclohexane
Temperature	mercury thermometers	red or green liquid thermometers
Storage of biological specimens	formaldehyde	ethanol or other preservatives
In-phase change and freezing point depression	acetamide	stearic acid
Qualitative test for halide ions	carbon tetrachloride	cyclohexane
Measurement of vapor pressure-temperature by isotensiscope	carbon tetrachloride	isopropyl alcohol
Acid-base experiments	conventional acids conventional bases	vinegar ammonia

Table from *Less is Better* and Freeman, 1995, pg. 511

10 Alternatives to Wet Chemistry

In addition to substituting safer chemicals and reducing the scale of experimentation, you might also want to consider avoiding certain experiments altogether. While hands-on wet chemistry experience is important to a certain degree, there are good reasons for exploring alternatives such as instrumental analysis, computer simulation, or even videos. One important consideration is that commercial and industrial laboratories are moving away from wet chemistry and towards instrumentation and simulation whenever possible, so it is important for students to gain experiences with these techniques. In addition, of course, these techniques offer a means of minimizing or avoiding some chemical wastes.

Instrumentation

Sample separation, purification, and other new techniques and equipment have advanced significantly in the last decade. However, many of the new instruments can be expensive, and can require users to be rather sophisticated. By and large, these instruments are more applicable to higher-level university chemistry classes than to introductory chemistry courses.

Chapter 8 discussed several instruments related specifically to microscale experimentation. In addition, there are a number of other instruments that can perform important laboratory analyses with reduced chemical input requirements. Some of these instruments include:

- ion, liquid, and gas chromatographs
- mass spectrophotometer
- IR and UV spectrophotometer
- nuclear magnetic resonance (NMR)
- atomic absorption instrument
- X-ray diffraction instrument

These highly sensitive instruments can reduce the quantities of analytes required for testing by 10- to 100-fold. For example, NMR analysis requires a 1 mL sample for quantitative analysis.

Again, many of these instruments may be beyond your budget, or may be inappropriate for the scale of your classes. However, keep in mind that just like other technologies (e.g., computers), they may become more affordable and easier to use in time.

Sample preparation

Another area where alternatives to wet chemistry exist is in the preparation of samples for analysis. Most samples require some extraction and/or concentration in preparation for further analysis. Traditional procedures (liquid-liquid or liquid-solid extraction) are time-consuming and waste substantial quantities of solvents. Solid phase microextraction (SPME) and supercritical fluid extraction (SFE) are two recently developed methods that eliminate the need for solvent to separate analytes. (These methods may not be relevant for high school laboratories.)

SPME is a solventless sample preparation method for analysis of organic compounds by gas chromatograph (GC). This approach replaces traditional methods such as purge and trap systems or liquid-liquid extraction. Essentially, SPME is a modified syringe holding a phase-coated fused silica fiber that adsorbs organic analytes when placed in the water sample. The analytes are then desorbed from the fiber into a capillary GC column at the heated injection port. The equipment is fairly small and reasonably priced, and the fibers are reusable up to 100 times. SPME is particularly cost effective when you consider the savings in solvent purchase and disposal.

SFE uses the unique characteristics of supercritical CO_2 to extract analytes from a sample, fully eliminating solvent use. Because supercritical fluids have lower viscosity and diffuse more rapidly into a sample, it also greatly reduces sample preparation time. The smaller, more recent SFE equipment models may be appropriate for some classroom settings. These models offer microprocessor controls as well as an elimination of moving parts to make maintenance and use easier. A typical extraction takes about 30 minutes at a material cost of about 10 cents.

Computer simulation/videos

Again, it is important that students gain laboratory experience in using glassware and equipment. However, due to time constraints in lab courses, and the length of typical introductory experiments, computer simulation may allow students to see a wider variety of experimental results, without generating wastes, and in a much shorter time period. At higher level educational institutions, computer simulation may greatly decrease the amount of chemicals (and wastes) required in research and development by allowing researchers or students to tweak and optimize experiments on a computer instead of repeating experiments again and again at a bench-scale or full-scale level.

A number of computer software vendors are producing chemical reaction simulation software. In some cases, this software is quite elaborate and complicated, as it is oriented towards commercial and industrial applications. In other cases, the software might be useful in the classroom. A good resource for more information (in addition to your local software store) might be a regional or state university, many of which have already started to implement simulation software. In addition, more and more information is being provided on the Internet.

In addition to computer simulations, you might also be able to teach certain experimental principles by using videos—even "home grown" videos.

11 Reusing and Recycling Chemical Resources

After doing as much as possible to minimize waste generation through source reduction, the next most preferable options are recycling and reuse. Although people tend to avoid recovery efforts because of the "costs" involved, chemicals can often be recovered at net costs lower than the cost of disposal. Reuse and recycling can occur at a number of points in the chemical use cycle. Some options include recovering chemicals as part of the experimental process, participating in a chemical swap, including recovery activities as part of the experiment. Again, some of these options will only be appropriate for larger, more advanced laboratories; others—such as the chemical swaps—may work even if you have a smaller program.

Recovery in process

Recovery of chemicals can serve as a valuable learning tool for students and can be presented as the final step of a chemistry experiment, or can be an "extra-credit" opportunity for interested students. (Caution: Recovery methods should always be performed under supervision.)

The College of the Redwoods, located in California, has designed a series of "closed loop" experiments where the by-products of one experiment become the reagents/reactants of the next experiment. At the end of the series, the by-products of the final experiment are available for the next set of students to start the process all over again. See the reference list in Chapter 15 for more information on this "no waste" lab manual.

Chemical swaps

Finding a use for surplus opened containers of chemicals is a good way to avoid having to dispose of them as waste. In many cases, laboratories or other users may be able to use these chemicals even though they have a lower purity. In addition, outside organizations may be willing to accept waste streams from laboratories if they can economically recover the valuable constituents. (Note: waste transport is subject to state/local regulations.)

Some things you can do to encourage chemical swaps/waste exchanges:

- Talk with other schools in your area to see if you can set up a simple exchange mechanism for school district.
- Consult the Merck Index to see what types of manufacturers in your area may be interested in your chemicals. For example, artisans may use metal salts for ceramic glazes; auto shops may be able to use distilled solvents for parts cleaning. This is most likely to happen with unused raw material that is properly labeled and in good condition.

When in-house or inter-school exchanges are not possible or too difficult to set up, external surplus exchange services might be helpful. Most exchange services are non-profit; some target educational laboratory institutions, some target industry, and some target both. Services are mostly regional to minimize transportation of potentially hazardous wastes.

Passive surplus exchange services allow generators to "advertise" for free their chemicals and waste materials that may be of use to others. A "catalog" is published every few months, or an on-line database (dial in on a modem) may be available. Items are listed as "wanted" or "available." (You can help close the recycling loop by obtaining chemicals for your lab from the "available" section.) Passive services rely on advertisers and readers to communicate directly to negotiate any exchanges.

Active exchange services, and/or chemical brokers may be able to find (or provide tips on how to find) market alternatives for reusable chemical wastes. Brokers charge a fee for an exchange, but may offer a free consultation visit to inform you of potential customers for your chemicals. Some state agencies can provide information on waste or chemical exchange services in your area. Remember that containers must be properly labeled and in good condition.

Solvent recovery

If you regularly generate spent solvents, recovery can be very cost-effective, as well as environmentally sound. Spent solvents that are properly segregated (see Chapter 13) can be easily distilled in-house to a high purity that will allow multiple reuse of the same batch of solvent. Many solvents are excellent candidates for distillation, including xylene, methanol, acetone, and toluene. Some exceptions are peroxide-forming solvents, which should not be distilled, and ethanol, which may require a permit for distillation.

In-house, bench-top distillation units ("stills") are commercially available, or can be set up at little or no additional cost with existing laboratory equipment. However, it is important to consult your local fire department before you consider purchasing or setting up a still, since most fire departments have regulations that apply to stills used to process flammables. You should also check with your state environmental agency to be sure your distillation activities conform to regulations. Alternatively, you may be able to contract with off-site recyclers to recover used solvents, depending on the quantity of solvents you generate.

If you use high-performance liquid chromatography (which tends to generate a substantial quantity of used solvent), you should know that automated, in-line solvent recovery systems are available that make it very easy to recapture up to 80% of high-purity solvents. The recovery equipment is fairly small, is low-maintenance, and requires minimal attention. The recovered solvent can be reused again and again. Such systems are available for a few thousand dollars and can pay for themselves in about one year due to reduced solvent purchases and waste disposal fees.

"The recovered solvent can be reused again and again.

Metal recovery

Many heavy metals have been largely phased out of chemistry experiments, although mercury, silver, and others may still be used. Even small amounts of these metals can be successfully recovered in the laboratory, possibly as an educational exercise (see page 39). For larger quantities, local or regional industries may be interested in metal-bearing wastes for recovery of the metals. In fact, the original suppliers may be interested in taking back such wastes for credit and/or recovery.

A few companies in the U.S. recover and clean contaminated mercury for reuse. It is possible to develop a closed-loop system whereby your mercury wastes are purified and returned to you specifically. These companies provide DOT-approved containers for accumulation and transport. Types of mercury accepted for recovery, recycling, or purification include spill debris, liquid mercury, and mercury in switches, thermometers, barometers, fluorescent lamps, and other items.

Mercury Reclaimers	Phone Number
Bethlehem Apparatus Company, Inc., Hellertown, PA	(610) 838-7034
Mercury Refining Company, New York, NY	(800) 833-3505
Quicksilver Recycling, Brisbane, CA	(415) 468-2000
Remlinger, D. J., Seattle, WA	(206) 296-4899

In-house recovery methods also exist, but it may be easier (from a safety and regulatory perspective) to allow the experts to handle and purify mercury considering its hazardous and toxic characteristics.

Silver reprocessors are more common than mercury reprocessors and can probably be found with a little snooping in the local yellow pages (starting with "Precious Metals" or "Silver" or "Refiners" or "Photographic Equipment or Processing"). Many of these reprocessors focus on photoprocessing wastes, but some may be able to handle general laboratory waste as well. Eastman Kodak publishes a directory (Number J-10B) of silver services, listing the names and locations of 188 firms in North America that recover silver. Such companies may take silver wastes for a nominal fee, or possibly for free if cost-effective recovery is possible.

In-house recovery of silver from solutions of its salts, via the chemical procedure shown below, can achieve purity of about 99.9%. In addition, there are commercially available electrolytic units or cartridges that are designed specifically for extraction of silver from photographic solutions.

An Example Experiment: Recovery of Silver

$$Ag^+ + NaCl \rightarrow AgCl + Na^+$$

$$AgCl \xrightarrow{Zn H_2SO_4} Ag + \text{soluble Zn salts}$$

1. Acidify the salt solution with 6M nitric acid (to pH paper of about 2).
2. Treat with a 10% excess of 20% aqueous sodium chloride solution.
3. Collect the precipitate (AgCl) in a filtered funnel and wash twice with warm 4M sulfuric acid and twice with distilled water.
4. Dry the AgCl and grind to a find powder.

CAUTION: *Because of the hydrogen, perform in a hood away from any source of ignition.*

5. In a fume hood, thoroughly mix 100 grams of dry AgCl with 50 grams pure granulated zinc metal and stir with 500 mL of 4 N H_2SO_4.
6. When the zinc has dissolved, decant the supernatant solution and mix the crude silver with another 50 g of pure granulated zinc and treat with 500 mL of concentrated of 4 N H_2SO_4.
7. After the zinc has dissolved, carefully add about 5 mL of concentrated H_2SO_4 and heat the mixture to 90° Celsius and stir for several minutes.
8. Separate the silver by filtration and wash with distilled water until the washings are free of sulfate. A sample of the resulting silver should give a clear solution in concentrated nitric acid.
9. If AgCl is still present, the solution will appear turbid and treatment with zinc and 4 N H_2SO_4 should be repeated.
10. The zinc salt solutions can be precipitated for disposal. (Note: These solutions – and other chemical solutions – should not be flushed down the drain without careful consideration of alternatives and review of local regulations.)

(Reference: Prudent Practices for Disposal of Chemicals from Laboratories, p 46. 1983)

12 Segregating Waste Streams

Segregating laboratory wastes during handling, storing, and lab packing is important for safety reasons, for legal reasons, for pollution prevention reasons, and for ensuring the lowest disposal costs. Many of the ideas presented in Chapter 5 on Managing Inventories can also help you manage wastes.

Segregation of incompatible materials in a storage area is critical. Ignitables should be separated from oxidizers or sources of ignition, especially solvents. Acids should be separated from bases, and oxidizing agents from reducing agents. There are also more specific chemical incompatibilities that you might want to consider during waste storage—these can be found in waste management publications or in the references cited in Chapter 15.

Hazardous and nonhazardous wastes should not be mixed together. Likewise, organic and inorganic waste streams should be segregated. For example, if you mix solvents with oils (e.g., from auto shop), you can expect to pay up to five times the disposal cost because the waste is now mixed. Segregating wastes within the same material type is also important, especially in the category of organic wastes.

Waste streams that you can recycle, especially recoverable metals or solvents, should be stored separately. In some cases, segregation will be important to facilitate recycling. For example, halogenated solvents and non-halogenated solvents should always be stored separately, since they need to be distilled separately. In particular, chlorinated solvents (which you might want to avoid using altogether) should not be mixed with non-chlorinated solvent wastes.

If a contract disposal service prepares your lab packs, they should provide accumulation and storage instructions for proper waste segregation. If you prepare your own lab packs, you will need to follow waste management regulations.

13 In-Laboratory Treatment of Wastes

As a last line of defense in efforts to minimize waste generation, you might want to consider options for in-laboratory treatment of wastes.

An important distinction exists between recycling or reclamation of chemicals and treatment of chemical waste. Reclamation or recycling generally applies to efforts to recover chemicals for reuse—either in the laboratory or elsewhere. By contrast, treatment generally applies to efforts to make waste less hazardous, followed by disposal. While treatment may be a useful activity, you should be aware that the treatment of hazardous waste may require a permit or be subject to regulation.

In the laboratory setting, treatment that occurs as the last step in an experiment is technically not covered by regulation. Therefore, you will be in the best position if you can fold the following treatment options into your experiments directly. In some cases, however, you may need to accumulate wastes before treatment is practical. In this case, you should consider discussing any treatment options with state or local regulatory agencies before you implement them in your laboratory.

Types of treatment techniques for rendering compounds non- or less hazardous—or in some cases reusable—include:

- neutralization
- separation
- fixation
- oxidation
- precipitation
- degradation
- ion exchange

Another possible treatment technique—thermal treatment—is not recommended due to regulatory concerns.

Neutralization of acids and bases is probably the most commonly used treatment method in educational institutions. Neutralization reduces a material's corrosivity (acid or caustic properties) by raising or lowering the pH to a neutral range, between 6 and 9.

Examples of some laboratory wastes amenable to treatment or neutralization are:

- phenol – with hydrogen peroxide and iron catalyst
- acid halides and anhydride – by hydrolyzing using sodium hydroxide solution
- hydroperoxide – by addition to acidified ferrous sulfate solution,
- metal hydride – through gradual addition of methanol, ethanol, or N-butyl alcohol
- soluble metal fluoride – by treating aqueous metal solutions with calcium chloride solution
- finely divided metal – by oxidation with water
- aqueous solutions containing toxic metal ions, precipitate as insoluble sulfides using sodium sulfide in neutral solution.
- oxidizing agents (e.g., hypochlorite or chromate) – by reduction using sodium bisulfite

Again, before you implement any treatment methods outside of the experimental process, you should discuss your plans with state or local regulatory agencies.

14 Working with School Administrators, Students, Other Schools, and the Community

Previous chapters of this handbook have discussed ways that you can minimize laboratory waste. Some of the suggestions, such as using a first in/first out inventory rotation, can be implemented at little or no cost; others, such as implementation of microscale chemistry, may require substantial outlays of money or time. Even though many of the techniques discussed in this handbook will save money in the long run, the up-front costs may be prohibitive.

Don't become discouraged. You can do a lot to minimize waste by following the simpler suggestions in this handbook. We've included sophisticated approaches to waste minimization in this handbook because large school districts may be able to implement them. We've also included them so that you are aware of what can be done.

However, you may find that, with a little creativity, you are able to afford to implement techniques that originally seemed too expensive. This chapter discusses ways of reducing the costs of waste minimization programs by working with others who are facing the same problem or whose business is to help waste minimization programs.

The role of school administrators

Your school's administrators can

- secure necessary funding and other resources
- play an active role in helping you carry out your program (for instance, by interacting with chemical suppliers or tracking waste minimization savings)
- identify other schools and institutions carrying out similar programs that can aid your efforts

- provide special services that will help your program, such as identifying sources of federal grants to apply for.

School administrators may not initially recognize the importance of waste minimization in your activities, or realize how waste minimization can benefit the school. This may simply be because they don't speak the technical language (for example, they may not know why chemicals like carbon tetrachloride are bad for the environment). Or maybe your administrators do not realize the bottom-line savings that a waste minimization program can provide, or how waste minimization benefits the school's community.

However, administrators, like teachers, students, and your community, are concerned about the environment. You may be amazed at the amount of support you receive once they understand the environmental, financial, and community benefits of waste minimization activities.

The role of students, other schools, and the community

Students are increasingly sensitive to the environment, but often do not realize how it translates into specific practices that, cumulatively, can make a big difference. Involving students in waste minimization is a good way to tap into their environmental enthusiasm and channel it toward practical ends. Students are often the most receptive to change.

Other schools in the area may be good sources of information, particularly colleges and universities. They may also have access to resources that you are unaware of. By teaming with other schools, you can make a good case in your district for increased support. If you are the first in your school district to be adopting pollution prevention, then sharing your experiences underscores your leadership and commitment.

Also consider the interest and support your local community can provide in terms of in-kind support and public recognition. Community support is a good way to sustain enthusiasm for the waste minimization efforts you undertake.

A strategy

Perhaps the best strategy for working with administrators is to forge a cooperative series of efforts so that key people are involved. Consider the following:

- Increase awareness through informal dialogue, e-mail, or presentations on what the school is doing, and how it is benefiting the environment, the school budget, and the community.
- Draft a written statement of the school's commitment to environmental quality and waste minimization.
- Provide a forum or suggestion box for waste minimization. Reward or recognize good waste reduction ideas.
- Set achievable laboratory- and school-wide waste reduction goals, (e.g., a 25% reduction in hazardous waste; or a 25% reduction in solid waste).
- Track and report progress. This can be done by identifying waste volume reductions, estimating annual savings in materials, storage, and disposal costs, and reporting overall achievements in relation to baseline goals.

Securing funding

> "You have a better chance of securing funding by demonstrating that pollution prevention efforts pay off.

Even if your administration is 100% behind you, they may provide you with little more than encouragement and moral support. We realize that resources in schools are constrained and waste minimization efforts are vying with many other worthwhile activities for funds. You will have a better chance of securing internal funding if you can demonstrate that your pollution prevention efforts are paying for themselves, which is true in most waste minimization programs. We recommend that some portion of the savings that your waste minimization team identifies should be reinvested into the waste minimization program. This provides tangible incentives to team members and administrators to sponsor waste minimization at your school and in your laboratory.

Fortunately, there are outside organizations that may be able to provide you with additional resources.

- The National Science Foundation (NSF) has supported a number of schools in upgrading to microscale. The NSF also helps to fund educational forums; for instance, they sponsor the free week-long courses in microscale chemistry given by the National Microscale Chemistry Center.
- State and local agencies may be interested in funding (or at least subsidizing) pollution prevention programs, especially at educational institutions.
- EPA's Office of Pollution Prevention and Toxics (OPPT) has sponsored universities in conducting basic chemical research in pollution prevention, such as with the OPPT Design for Environment Program. Contact the EPA office in your area for additional information.
- Resources may be available from the education community, including from such groups as the National Science Teachers Association. Local PTAs can also be a good source of funding and are generally responsive to environmental issues.
- The American Chemical Society (ACS) has a grant program called PROJECT CHEMISTRY, which may be able to support your program. (Chapter 15 has ACS address information.)
- Local businesses and organizations like to support K-12 education (and receive publicity for supporting the community). A selling point with such organizations is that it's for education *and* for the environment. Organizations such as Rotary, Lions, Kiwanis, and the local Chamber of Commerce are good places to seek private sector support.
- Local, or even national, equipment companies are sometimes willing to offer free use of or discounts on their equipment. Another tactic might be to request use of equipment on a trial basis to prove its fitness.

Outreach and communication

A sure way to build support over the long term is to reach out to your community and inform them of your activities. The same applies for other schools who are wrestling with the same issues, and may have effective solutions to the problems you encounter.

- Networking with other schools is a good way to identify common problems, funding sources, success stories, and build overall support.
- Networking with colleges or universities in your area may be particularly helpful, as they often have experience to share regarding pollution prevention.
- Communicating your program to the community through various forums and speaking opportunities is a good way to show your school's commitment to preventing pollution and becoming more efficient.

Communicating the results of your pollution prevention activities is a good way to demonstrate to administrators that your program is paying off, and sustain long-term commitment to your efforts.

15 Getting More Information

Here is a list of organizations and publications that may be of help to you as you establish your pollution prevention program.

Organizations

- National Science Foundation – (703) 306-1234
- U.S. Environmental Protection Agency (there are regional offices throughout the country)
- State government departments involved with environmental management, which usually have names such as Department of Environmental Conservation, Department of Health, or Department of Environmental Quality
- College Chemistry Programs and Pollution Prevention Programs.
- American Chemical Society, 1155 – 16th Street NW, Washington, DC 20036

Publications: Laboratory Waste Minimization

American Chemical Society. (1993). *Less is better: Laboratory chemical waste management for waste reduction* (2nd ed.). Washington, DC: Author.

American Chemical Society (1994). *Laboratory Waste Management: A Guidebook.* Washington, DC: Author

American Chemical Society (1995). *Model Chemical Hygiene Plan for High Schools.* Washington, DC: Author. Available on disk: MacOS or MS-DOS.

Environmental Protection Agency. (1990, June). *Guides to pollution prevention: Research and educational institutions.* Cincinnati: U.S. Environmental Protection Agency.

Field, R.A. (1986). *Management strategies and technologies for the minimization of chemical wastes from laboratories.* Raleigh: North Carolina Pollution Prevention Pays Program.

Illinois Department of Natural Resources. (1990, May). *Waste reduction guide for Illinois schools.* Springfield, IL: Author.

Kaufman, J.A. (Ed.). (1990). *Waste Disposal in Academic Institutions.* Chelsea, MI: Lewis Publishers, Inc.

National Research Council. (1983). *Prudent practices for disposal of chemicals from laboratories.* Washington, DC: National Academy Press.

Jacobson, L. (no date). *Children's art hazards.* New York: Natural Resources Defense Council, Inc.

State of Washington School Chemistry Lab/Storeroom Safety Committee. (1984). *Who should conduct high school lab/store room cleanups and assure safe disposal?* Contact James Knudson, Washington State Department of Ecology, Hazardous Waste Section, (206) 459-6203.

Task Force on RCRA. (1990). *The waste management manual for laboratory for personnel.* Washington, DC: American Chemical Society.

Wahl, G.H., Jr. (Ed.). (no date). *Reduction of hazardous waste from high school chemistry laboratories.* Raleigh: Pollution Prevention Pays Program, North Carolina Department of Natural Resources and Community Development.

Publications: General Waste Minimization

Freeman, H.M. (Ed.). (1990). *Hazardous waste minimization.* New York: McGraw-Hill Publishing Company.

National Renewable Energy Laboratory. (no date). *WasteWorld: Teaching students about municipal solid waste.* Municipal Waste Resource Management Program—Project Fact Sheet. Golden, CO: Author.

National Research Council. (1985). *Reducing hazardous waste generation: An evaluation and a call for action.* Washington, DC: National Academy Press.

Tulis, J.J., & Thomann, W.R. (Eds.). (1992). *Proceedings: Strategies for Improved Chemical and Biological Waste Management for Hospitals and Clinical Laboratories.* Raleigh: Office of Waste Reduction, North Carolina Department of Environment, Health and Natural Resources.

Publications: Laboratory Manuals

Bergstrom, W., & Howells, M. (1988). *Hazardous waste reduction for chemical instruction laboratories.* Cincinnati: U.S. Environmental Protection Agency.

College of the Redwoods. (1989). *No-waste lab manual for educational institutions.* Sacramento: California Department of Toxic Substances Control.

Ehrenkranz, D.F. (1993). *Chemistry in microscale: a set of microscale laboratory experiments.* Dubuque, Iowa: Kendall/Hunt Pub. Co.

Ehrenkranz, D.F. (1993). *Chemistry in microscale: a set of microscale laboratory experiments with teacher guides.* Dubuque, Iowa: Kendall/Hunt Pub. Co.

Flinn Scientific (1994). *Spectrophotometer Laboratory Manual.* Batavia.

Hathaway, R.A. (Ed.). (1991). *Safety considerations in microscale chemistry laboratories.* Symposium at the 197th national meeting of the American Chemical Society, April 12, 1989, Dallas. Washington, DC: American Chemical Society.

Mayo, D.W., Pike, R.M., Trumper, P.K., & Fickett, P. M. (1994). *Instructor's Manual, Microscale Techniques for the Organic Laboratory.* Third Edition. New York. John Wiley & Sons, Inc.

Mayo, D.W., Pike, R.M., & Trumper, P.K. (1994). *Microscale Organic Laboratory with Multistep and Multiscale Syntheses* (3rd ed.). New York: John Wiley & Sons, Inc.

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Mayo, D.W., Pike, R.M., & Butcher, S.S. (1989). *Microscale Organic Laboratory* (2nd ed.). New York. John Wiley & Sons.

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Pike, R.M. (Winter 1994). Microscale Chemistry - Small Scale, Big Idea. *EM Scientist, 3*(1), pp. 1-2.

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Waterman, E.L. (1993). *Small scale chemistry laboratory manual.* Menlo Park, CA: Addison-Wesley Publishing Co.

Waterman, E.L. (1993). *Addison-Wesley small scale chemistry.* Menlo Park, CA: Addison-Wesley Publishing Co.

Williamson, K.L. (1989). *Macroscale and Microscale Organic Experiments.* Lexington, MA: D.C. Heath and Company

A Appendix: Waste Minimization Checklist

The following checklist is designed to help you minimize the amount of waste generated in the laboratory. The list is not all-inclusive, but should serve as a starting point for your efforts.

Purchasing Chemicals

- ❑ Develop a purchasing strategy for chemicals and other hazardous materials.
- ❑ Purchase chemicals in smaller sizes.
- ❑ Standardize chemical purchases across classes or laboratories.
- ❑ Designate a single person to be responsible for purchasing chemicals and monitoring inventories.
- ❑ Link purchasing requests into an inventory system so that excess chemicals in stock can be used before buying more.
- ❑ Find a supplier who will accept unopened chemicals that are returned, or will otherwise support waste minimization efforts.

Managing Chemical Inventories

Institute inventory control

- ❑ Conduct a school-wide inventory to identify where chemicals are located.
- ❑ Designate a centralized place for chemical storage and another for waste storage, with spill containment.
- ❑ Organize your chemical and waste storage systematically to keep like chemicals together.
- ❑ Adopt a standard labeling procedure for chemicals and waste, using labels that are colorfast and permanent.
- ❑ Designate who is responsible for labeling and inventory control.

- ❒ Use tags, bar codes, or some other system to establish a computer tracking of chemicals.
- ❒ Use a first-in/first-out policy.
- ❒ Return expired material to supplier.
- ❒ Perform regular inventory audits to identify chemicals that aren't being used.
- ❒ Provide a simple regular listing to chemical users on available chemical stocks, location, and point-of-contact.

Work on spill and leak prevention

- ❒ Keep chemicals and waste containers covered to prevent spills.
- ❒ Install spill and leak protection in chemical storerooms, including berms, sumps, or even simple plastic containers.
- ❒ Anchor storage cabinets to walls and floors.
- ❒ Periodically inspect stored chemicals for signs of leakage, poor storage practices, or any other problems.
- ❒ Keep a record of spills and leaks and note why they happened and how they can be avoided in the future.

Conducting Experiments

Teach resource-efficient policies

- ❒ Use solvents and other hazardous materials sparingly.
- ❒ Have students monitor reactions closely and add only what's needed.
- ❒ Emphasize conservation of water, electricity and other general resources.

Set up experiments with waste minimization in mind

- ❒ Pre-weigh chemicals for students.
- ❒ Have students work in teams.
- ❒ Demonstrate some experiments rather than having the entire class perform them.

- Use spent/recovered solvents for an initial rinse and fresh solvents for a final rinse.

Include final steps in experiments to destroy or inactivate hazardous substances

- Neutralize acids and bases.
- Perform chemical conversions to non-hazardous substances.
- Provide students with the opportunity to research waste minimization techniques.

Scaling Down Experiments

- Reduce scale of experiment (and associated quantities of chemicals) where possible.
- Move to microscale chemistry.

Substituting Materials

Substitute less hazardous chemicals for more hazardous ones

- Use laboratory detergents rather than hazardous cleaning baths (e.g., substitute detergents for chromic acid solutions).
- Use non-halogenated rather than halogenated solvents (e.g., substitute cyclohexane for carbon tetrachloride).
- Use less toxic/hazardous solvents rather than more toxic/hazardous solvents.

Finding Alternatives to Wet Chemistry

- Substitute computer simulations, videos, etc. for actual experiments.
- Use alternatives to solvent-based extraction (e.g., Solid Phase Microextraction or Supercritical Fluid Extraction).
- Use instruments in place of wet chemistry (e.g., chromatography, spectrophotometry, atomic absorption, nuclear magnetic resonance, X-ray diffraction).

Reuse and Recycling

Establish a chemical swap

- ❒ Set up an internal surplus chemical exchange.
- ❒ Participate in an outside chemical/waste exchange program.

Reclaim solvents

- ❒ Filter spent solvent for reuse.
- ❒ Distill spent solvents on-site.
- ❒ Recycle solvents via a solvent recycling service.

Reclaim metal-bearing waste

- ❒ Identify an outside industry interested in taking metal-bearing waste for recovery.

Segregating Individual Waste Streams

Segregate wastes

- ❒ Keep hazardous waste separate from non-hazardous waste.
- ❒ Keep organic waste separate from inorganic waste.
- ❒ Keep different groups of solvent separate (e.g., halogenated vs. non-halogenated solvents).
- ❒ Keep incompatible materials separated (ignitables and oxidizers; acids and bases; oxidizers and reducers, etc.).

In-Lab Treatment

- ❒ Neutralize acids and bases
- ❒ Perform chemical conversions to create non-hazardous substances

Strategies for the Entire School

Create a Lab or School-wide Program

- ❒ Create a waste minimization team composed of students, teachers, and administrators.
- ❒ Develop a written statement of commitment to waste minimization.
- ❒ Perform a waste audit of the school/lab.
- ❒ Provide a forum or suggestion box for waste minimization/pollution prevention ideas.
- ❒ Set up waste minimization education sessions for students/staff.
- ❒ Set up specific reduction goals (e.g., 50% reduction in amount of waste generated per year).

Implement other (non-laboratory) waste minimization/pollution prevention opportunities

- ❒ Perform routine maintenance of school equipment to fix leaks, avoid accidents.
- ❒ Reduce use of fertilizers and pesticides on school grounds.
- ❒ Compost grass and other trimmings.
- ❒ Keep school vehicles properly tuned up.
- ❒ Maintain air conditioner and heater filters to reduce energy consumption.
- ❒ Replace inefficient lighting with compact fluorescent or other energy-smart lighting.