Spring 5-2012

Developing Environmental Sustainability Criteria for University Research Laboratories: A Tool for Rating and Implementing Green Methodology in Labs

Maxine White
University of Nebraska-Lincoln

DEVELOPING ENVIRONMENTAL SUSTAINABILITY CRITERIA FOR UNIVERSITY RESEARCH LABORATORIES: A TOOL FOR RATING AND IMPLEMENTING GREEN METHODOLOGY IN LABS

By

Maxine White

AN UNDERGRADUATE THESIS

Presented to the Faculty of
The Environmental Studies Program at the University of Nebraska-Lincoln
In Partial Fulfillment of Requirements
For the Degree of Bachelor of Science
(or appropriate degree)

Major: Environmental Studies and Biological Sciences

With the Emphasis of: Biology

Under the Supervision of Dr. Mark Burbach

Lincoln, NE

May, 2012

DEVELOPING ENVIRONMENTAL SUSTAINABILITY CRITERIA FOR UNIVERSITY RESEARCH LABORATORIES: A TOOL FOR RATING AND IMPLEMENTING GREEN METHODOLOGY IN LABS

Maxine White, B.S.

University of Nebraska-Lincoln, 2012

Advisor: Dr. Mark Burbach

This study examines sustainable behavior and methodology in university research labs. Environmental problems like global warming are becoming common knowledge to many people throughout the world, and it is necessary for humans to live in more sustainable ways that leave a healthy planet for future generations. Universities are an important part of the global community, and it is pertinent that they become more involved in sustainable efforts. University research laboratories produce large amounts of regular and hazardous waste, use massive amounts of energy, and are currently not operating in sustainable ways. The purpose of this study is to determine the criteria of sustainable research labs and how these can be used to implement green methodology in labs. A literature review was performed to determine the criteria, and these were used to

create a Lab Sustainability Checklist that can be used to help labs become more sustainable. The established criteria fall into five categories, including: energy conservation, green chemistry, waste reduction, sustainable management practices, and water conservation. The most common criterion found in the literature involved educating and training researchers, lab employees, and students about sustainable best practices in the lab, and this will be key to improving sustainability. While there are many barriers to lab sustainability, improvements in technology and education can go a long way in implementing sustainable practices.

Introduction

Sustainability has become an important concept in operating businesses, organizations, and universities. Evidence of environmental damage that threatens the livelihood of Earth and many of its organisms has amounted and human contributions to the damage have become clearer. The threats associated with global warming and massive waste production, which has caused contamination of the natural and human environment, are just two examples of damage that must be addressed (Wright, Ironside, & Gwynn-Jones, 2008). Universities often have funding and resources available to research sustainability and methods to achieve it, and many universities have begun implementing programs to increase their sustainability. The University of Minnesota and the University of Wisconsin-Madison are two of only eight schools to receive an ‘A’ from the College Sustainability Report Card, which evaluated campus sustainability at over 300 colleges, while the University of Nebraska-Lincoln received a ‘C’ for 2011 (The College Sustainability Report Card, 2011).

University research laboratories foster the pursuit of knowledge and help humans find solutions to problems occurring within local and global communities, but these labs can also create problems. It is difficult for research labs to function in sustainable ways, because they require large amounts of energy to keep analysis equipment, freezers, fume hoods, computers, and many other energy-powered devices in operation. Further, they may not have up-to-date, energy efficient equipment because initial outlay for such purchases are high (Dahle & Neumayer, 2001). Collectively, they produce massive quantities of waste, much of which is considered hazardous in some way; therefore its disposal is heavily regulated and has the potential to cause pollution (Dahle & Neumayer, 2001; Rau et al., 2000).

Hazardous waste can range from biohazard materials, such as human or animal blood or other bodily fluids containing infectious agents or genetically altered materials, to dangerous chemicals and radioactive materials, all of which must be disposed of in expensive, regulated methods (Rau et al. 2000). Regulations are set up by federal agencies like the Environmental Protection Agency (EPA), the Food and Drug Administration (FDA), and Department of Transportation (DOT), state agencies like the Nebraska Department of Environmental Quality, and university organizations.

A key process in the disposal of biohazard materials is decontamination through use of toxic chemicals, sterilization by high temperatures in autoclaves, or incineration (Rau et al., 2000). While most of the waste coming out of research labs is considered hazardous, it is often not thought to be more dangerous than waste coming from medical facilities. The EPA determined disease-causing agents in medical waste to be less harmful than household waste in the Medical Waste Tracking Act of 1988, since the disease-causing potential is highest when the waste is created and only reduces thereafter (Rau et al., 2000). Much of the waste in labs is treated as hazardous even if it is not, as a precautionary principle and sometimes lack of time, which prevents many of the materials from being reused or recycled. This contributes to accumulation of plastics in landfills, which also poses a threat to the environment, since most plastics used in labs are not considered biodegradable (Albertsson & Huang, 1995).

Considering the environmental problems created by research labs, it is important to investigate measures to reduce waste, and the use of energy and water, and to implement sustainable management and pollution prevention strategies to increase sustainability. Specialized procedures may have to be designed to achieve sustainability given the regulations and hazards posed by wastes produced from research labs (Wright et al., 2008). The purpose of this study is to determine the behavioral and management criteria of a sustainable research lab and use this information to develop a rating system or guide to establishing sustainable research methods and operations in labs.

Literature Review

Wright et al. (2008) performed a study that examined the barriers to lab sustainability at Aberystwyth University in the United Kingdom (UK). They developed a questionnaire that examined lab employee's thoughts on sustainability within the lab, what types of barriers prevented sustainable practices, and possible sustainability improvements. They found that most university researchers thought sustainable methods should be included in the laboratory, that these methods would not degrade the quality of their research, and that their sustainable efforts could make a difference. When asked to consider the barriers to sustainable behavior in labs, participants selected limited time, limited support, and deficient information as barriers that may prevent their ability to perform in sustainable ways. The researchers also found that most respondents thought costs or monetary benefits would have the strongest influence over increasing sustainability in labs, and that it would be necessary for both technology and behavior to change.

While human behavior plays a large role in whether or not labs are sustainable, lab sustainability is also limited by government regulations. In 2000, The National Association of Physicians for the Environment (NAPE) created several committees to investigate waste management at hospitals and biomedical research facilities to determine whether minimization is possible and if sustainable alternatives exist. Rau et al. (2000) reported the findings of the committees. Research labs often work with chemicals that are hazardous to human health and the environment, and while they usually only generate small amounts of these wastes, disposing of them becomes problematic because there are hundreds of different chemicals in use at any one university and each must be disposed of separately.

Many lab chemicals qualify as acids, which are often caustic and can burn the skin, or bases, which are corrosive and also can burn the skin. Fumes produced can cause respiratory problems and some chemicals are considered carcinogens. Chemicals can also be mutagens, which mutate DNA and RNA causing harm to organisms and possibly altering their genes, and teratogens, which are harmful to pregnant women. Material Safety Data Sheets (MSDS) come with all chemicals purchased for use in labs and they explain dangers involved in handling the chemicals, including those mentioned above, as well as many others. Labs also produce biohazard, radioactive, pharmaceutical, and multihazard wastes, all of which have different regulations that apply to their disposal. The costs for managing these wastes begin to add up, since many must be shipped elsewhere for one or more treatments before they can go to a landfill, while others must be stored for several years (Rau et al., 2000).

Implementing "green chemistry" can reduce the amount of hazardous chemical wastes produced at university research labs. Green chemistry involves using chemicals that are not hazardous and produce no hazardous products in their making or design (Goodwin, 2004). In order to determine which chemicals are too hazardous and which are safe, risk assessment must be performed using Material Safety Data Sheets (MSDS) and care must be taken to distinguish between actual and perceived risks (Goodwin, 2004). While there are not yet replacements for all hazardous chemicals, labs can, for instance, be selective in what kinds of solvents they use to reduce their environmental impact. Water, ethanol, acetic acid, acetone, ethyl acetate, 2-propanol and several other solvents are all less harmful than the other current options, especially when used in small quantities (Goodwin, 2004; Sherman, et al. 1998). Green chemistry has become more popular, despite some doubters in the chemistry community, and has even received recognition with the Presidential Green Chemistry Challenge Awards (Goodwin, 2004). With all of the research being done on green chemistry, it is likely that in the future there will be many more options in the realm of environmentally friendly chemicals.

Besides all of the waste generated from chemicals and other materials mentioned above, plastic and glass containers are used in many experiments performed in labs. These containers are used to hold chemicals, act as vessels for reactions, and store cells or other biological fluid. Sometimes regulations require containers to be disposed of in the same way as the waste they held, which means they will eventually end up in the landfill instead of being recycled (Rau et al., 2000). Glass materials are recyclable, however, it may be more green for labs to retain these materials and wash them for reuse when safe, which in turn may reduce the use of plastic within labs. The accumulation of plastics in landfills is problematic because these materials are made of synthetic polymers that were designed to be durable and are not considered biodegradable (Albertsson & Huang, 1995).

Plastic materials typically have a recycle symbol on them with a number in the center, indicating what type of resin it is made from and whether it can be recycled (US EPA, 2011). In Lincoln, Nebraska, some recycling facilities will take all plastic materials labeled one through seven, but some plastics produce harmful byproducts when recycled and many companies choose not to recycle these (US EPA, 2011). Additionally, many plastics are never recycled because it has not yet become a social norm in the US. In 2009 alone, the United States produced 30 million tons of plastic waste, and only seven percent of this was recycled (US EPA, 2011). With such massive amounts of plastic waste ending up in the landfill, it is clear that all sectors in the US must reduce the generation of plastic waste, including research labs.

Methods

A literature review was performed to determine the behavioral and management criteria of sustainable research labs. Electronic resources including JSTOR, Academic Search Premiere (EBSCO), Web of Science, and Google Scholar were used. The search terms included “green labs”, “sustainable research labs”, “campus sustainability”, “research lab energy efficiency”, and “green chemistry”. The criteria wer selected by including as many sustainable lab practices and management methods as possible that are commonly used or recommended in institutions. All of the criteria were compiled and organized into categories, and this information was used to create a form with a checklist for green research methods.

Results

Five broad categories of sustainable lab characteristics were common throughout the literature: energy conservation, green chemistry, waste reduction, sustainable management, and water conservation (Table I). Within each category, several criteria emerged. The first characteristic, energy conservation, can be accomplished in labs by replacing equipment with an Energy Star™ or other energy efficient equivalent (Coleman, Thorp, & Kalpowitz, 2009; Medlin & Grupenhoff, 2000; US EPA, 2012). Turning off lights, computers, and equipment when they are not in use can also reduce energy use (Coleman et al., 2009; Medlin & Grupenhoff, 2000). Closing fume hood or biological safety cabinet sashes or turning them off when they are not in use will significantly decrease a lab's use of energy (Coleman et al., 2009; Medlin & Grupenhoff, 2000; US EPA, 2012). Another method recommended to reduce lab energy use is minimizing use of autoclaves, which requires a lot of energy to produce the steam necessary for their use (US EPA, 2012). Defrosting freezers regularly can also reduce energy use, because it prevents the freezer from working harder to maintain temperature (Grimm, 2007).

Labs can also become more sustainable by using green chemistry. Common green chemistry methods in the literature include reducing overall use of chemicals, and performing smaller experiments that require smaller amounts of chemicals (Goodwin, 2004). Fundamental methods of green chemistry include replacing solvents that are dangerous to human health and the environment with sustainable solvents. Solvent substitution databases provide a resource for labs interested in reducing their impact on the environment while still performing the necessary reactions (Durham, Kramer, Ong, & Park, 2011; Goodwin, 2004; Sherman, et al. 1998). Universities can also implement chemical reuse programs by installing solvent distillation equipment, and can redistribute solvents to labs on campus as well as distribute excess unused chemicals from a lab to one that needs them (Durham et al., 2011; Goodwin, 2004). The final common aspect of green chemistry that would improve lab sustainability is having pollution prevention programs in labs, to ensure less harmful chemicals are being used and that they are disposed of properly (Durham et al., 2011; Goodwin, 2004; US EPA, 2012).

Waste reduction is another common method proposed to make labs greener. Recycling paper, product packaging, and recyclable plastics can significantly reduce lab waste (Grimm, 2007; Rau et al., 2000). Reuse of materials such as glass and plastic containers also reduces the waste coming out of the lab, especially because glass is expensive and difficult to recycle (Grimm, 2007). Strictly separating biological waste or other regulated waste to ensure biohazard, chemical, and radioactive waste does not contaminate other waste is another pertinent method of reducing regulated waste, by ensuring that recyclables remain uncontaminated (Messelbeck & Sutherland, 2000; Rau et al., 2000).

Sustainable management is a key component in improving lab sustainability. Using sustainable purchasing practices, such as buying environmentally friendly, recyclable, reusable, or post-consumer lab materials, was a common suggestion found in the literature (Grimm, 2007; Medlin & Grupenhoff, 2000; Messelbeck & Sutherland, 2000). Along the same lines, inquiring about environmentally friendly products when purchasing was noted as a crucial method of sustainable management (Dahle & Neumayer, 2001; Grimm, 2007; Messelbeck & Sutherland, 2000). Some organizations will develop a sustainable purchasing policy, in which only sustainable products may be purchased, and this was suggested as a means to increase sustainability (Medlin & Grupenhoff, 2000). Grimm (2007), along with Medlin and Grupenhoff (2000), suggested that labs avoid buying in excess, but keep good inventory to prevent leftover materials from becoming waste. Another crucial part of making labs green is educating employees in environmental best practices (Coleman et al., 2009; Dahle & Neumayer, 2001; Durham et al., 2011; Grimm, 2007; Medlin & Grupenhoff, 2000; Nicolaides, 2006; Wright et al., 2008). Developing systems where a lab's sustainability are rated and compared to other labs, and incentives are given to the most sustainable labs would be a good way to motivate labs to participate, (Durham et al., 2011, Wright et al., 2008). There are many resources online, such as databases and guides, that the EPA, Department of Energy, and other organizations have put together to give individuals more information on how to make research labs more sustainable; using these resources would help universities develop best practices criteria for their labs and keep them updated.

Water conservation is the final category necessary to implementing green methodology in the lab. It is important for labs to use purified or filtered water only when it is necessary, because a lot of water is wasted to filter the water (US EPA, 2012). Avoiding the purchase and use of equipment with single-pass cooling systems is also necessary to prevent wasting water (US EPA, 2012).

Discussion

The Lab Sustainability Checklist (Table I) can be used by universities to guide them in becoming more sustainable and help them monitor their progress. Energy conservation is a pertinent measure scientific research labs need to implement, because they use four to five times more energy than other buildings of comparable size to run and maintain their equipment and experiments (Coleman et al., 2009; Grimm, 2007; Woolliams, Lloyd, & Spengler, 2005). A simple technique to reduce energy consumption is defrosting lab freezers regularly to make sure the machine is operating at optimal conditions and not using more energy than necessary to maintain low temperature (Grimm, 2007). While conserving energy can save universities a lot of money, labs often do not see the importance of energy conservation because most labs do not have to pay the energy bill (Coleman et al., 2009). Turning off fume hoods or closing their sashes when they are not in used was found to save the most energy in labs that use them. The Massachusetts Institute of Technology (MIT) performed a study on energy saved by turning off or closing fume hood sashes when unused and found that the chemistry department alone saved $41,000 per year (Durham et al., 2011). Monetary savings provides an incentive for universities to enforce energy conservation practices in labs, which could be done by either using an incentive-based rating system or by issuing monetary costs for labs that do not reduce their energy use (Coleman et al., 2009; Wright et al., 2008).

Other barriers to energy conservation in research labs include perceived lack of time, and lack of information and awareness, (Coleman et al., 2009; Dahle & Neumayer, 2001; Grimm, 2007; Woolliams, Lloyde, & Spengler, 2005; Wright et al., 2008). Use of

Energy Star™ equipment in the lab is not yet common, which may be because energy conservation is not a concern when purchasing equipment, even though many people have heard of these products (Coleman et al., 2009). These barriers can be addressed by educating and training lab employees in environmental best practices and making sure the lab has enough staff to carry them out (Coleman et al., 2009; Grimm, 2007; Wright et al., 2008). Increasing availability of energy efficient and Energy Star™ equipment will also make it easier for labs to incorporate them in their purchasing policies. Individuals in the lab may also be resistant to energy conservation because time is already scarce in the field of research due to competition and time constraints, and taking extra steps to reduce energy use may seem as if it takes too much time or slows down the research process (Coleman et al., 2009; Grimm, 2007; Wright et al., 2008). When training and education lab employees about sustainability, it is important to make energy conservation salient to individuals and develop practices that involve cooperation to minimize the time necessary to perform them (Coleman et al., 2009; Grimm, 2007).

As technology improves, implementing green chemistry in labs gets easier. Decreasing the size of experiments along with overall reduced use of chemicals will help labs reduce excess waste, thereby saving labs money and may even improve accuracy of experiments (Goodwin, 2004). Many of the solvents used in research labs are dangerous to human health and the environment. However, more sustainable solvents are available now as well as several online resources (Table II) that can help labs find a suitable replacement (Sherman et al., 1998). These resources can also help labs define their pollution prevention strategies, which should be included in the education and training of employees to ensure dangerous lab chemicals are not making it into the water supply or other sectors of the environment (Goodwin, 2004; Rau et al., 2000; Sherman et al., 1998). Pollution can have various negative side effects on the environment and its ecosystems, as well as on human health. The field of green chemistry has been developing for several years now, and more sustainable options are becoming available for substitutions while still providing legitimate chemicals and results (Goodwin, 2004).

Collectively, research labs produce massive amounts of waste, with much of it classified as some kind of hazard. Making a rigorous effort to keep waste contaminated with biohazard, chemical, or radioactive waste separate from regular trash or recyclable materials, will help labs save money by reducing the amount of regulated waste they must dispose of and will reduce the amount of waste that must be autoclaved (Messelbeck & Sutherland, 2000; Rau et al., 2000; US EPA, 2012). Decreased use of autoclaves also reduces financial costs to universities, since less energy is required (Messelbeck & Sutherland, 2000). While most universities train lab employees on what qualifies as regulated hazardous waste and what does not, implementing a yearly refresher course and providing a small handbook in the lab as a reminder may improve a lab's ability to keep waste separated properly. The literature suggests that lab employees are not aware of what lab materials can be recycle or reused, therefore recycling and reuse information should be included in their training, and recycling containers in the lab should be more apparent as a reminder (Grimm, 2007; Wright et al., 2008).

One of the most important components of green labs is sustainable management practices. Purchasing eco-friendly products helps labs reduce their waste by allowing them to recycle and reuse more of their lab materials, and taking this a step further by implementing a sustainable purchasing policy at the university or specific lab in which only sustainable products are purchased, will help the lab reduce their waste even more (Medlin & Grupenhoff, 2000; Messelbeck & Sutherland, 2000). When purchasing, it is also important to ask companies whether they carry sustainable products and express interest in them. When companies observe an increased interest in eco-friendly products from their customers, they are more likely to include sustainability in their product research and design process (Dahle & Neumayer, 2001; Messelbeck & Sutherland, 2000). Since interest in sustainable lab products has increased, more companies are making such products available, making it easier for labs to purchase green lab materials (Messelbeck & Sutherland, 2000). When purchasing, it is also important to buy only what is needed at the time, and keeping detailed inventory will make this easier (Medlin & Grupenhoff, 2000). When labs avoid buying materials in excess, it prevents the products from becoming waste, which saves money when they have less regulated waste to dispose of (Grimm, 2007).

Considering two of the main barriers to lab sustainability are lack of information and awareness, it is not surprising that training lab employees in green methodology was the most common criterion in the literature (Coleman et al., 2009; Dahle & Neumayer, 2001; Durham et al., 2011; Grimm, 2007; Medlin & Grupenhoff, 2000; Nicolaides, 2006; Wright et al., 2008). This makes training all lab employees another crucial aspect of sustainable management practices. A key concept here is training individuals in environmental best practices before they start working in the lab, because this will catch them before they have developed bad habits and therefore have the strongest impact on improving sustainable behavior (Wright et al., 2008). People tend to be resistant to change, so it will be necessary to include why lab sustainability is so important and emphasize that their participation will help make a difference.

When designing and updating the green methodology for a lab, there are many resources available to management, including the solvent databases (Table II), EPA websites and databases, Labs of the 21st Century, a program sponsored by the EPA and Department of Energy, and many others (Sherman et al., 1998; US EPA, 2011, 2012). Once best practices have been developed, universities can use a checklist like the one seen in Table I and add a point system to it so labs can be rated and compared in their sustainability. The rating can then be used along with an incentive system, where the greenest labs receive rewards or recognition. Incentives are often successful in increasing participation in programs, and are likely to make lab sustainability more lucrative (Coleman et al., 2009; Wright et al., 2008). An alternative to incentives is to develop punishments for labs that are not sustainable, which could involve charging a fee, and is also likely to increase participation in lab sustainability programs (Coleman et al., 2009; Wright et al., 2000).

The final component of increasing lab sustainability is water conservation. Some of the equipment in research labs produces heat, and therefore requires a cooling system. Equipment that includes single-pass cooling passes cold water through the system once and then sends it out of the system, replacing it with new water (US EPA, 2012). Since this wastes large amounts of water, labs should avoid the use and purchase of equipment with this type of system (US EPA, 2012). Labs also use a lot of purified and filtered water for their experiments, and since the process of purifying and filtering the water wastes water, it is pertinent for labs to only use purified or filtered water when necessary (US EPA, 2012).

Future Research

This study is limited because many of the criteria developed may not apply to all labs, or the existing infrastructure at an institution may cause some of these measures to be inefficient. In the future, it would be insightful to use the checklist developed here, along with a survey, to examine the state of sustainability in university research labs. Performing a study to determine which of the five categories is the easiest to implement in the lab or which changes researchers, students, and lab employees are most willing to make, could give valuable information on where to begin with greening university research labs and how effective the changes are. Current studies show that lab workers suggest incentives, especially monetary, are most likely to spur change, however a study that looks at the effectiveness of incentives versus punishments would help find the best motivators for implementing green methodology.

Conclusions

Considering all of the variables involved in making research labs more sustainable, it is clear that the effort will require an interdisciplinary approach. Combining sustainable management methods with green chemistry, waster reduction, and conservation will not only require cooperation among representatives in each field to maintain a sustainable program but also among researchers, lab employees, and students. Most of the criteria outlined in this study involve sustainable management and behavior change, which suggests that education and training of employees and staff in charge of the sustainable lab program is paramount. Along with management methods, requesting sustainable research equipment and materials is also crucial, because it encourages suppliers to develop and provide them, and the more sustainable products that are available, the easier it will be for labs to become more sustainable and reduce their waste. The criteria developed in the Lab Sustainability Checklist were the most common in the literature and would be a useful guide for universities to begin implementing green methodology in research labs.

Literature Cited

Albertsson, A., & Huang, S. J. (1995). *Degradable polymers, recycling, and plastics waste management*. New York, NY: Marcel Dekker, Inc. Retrieved from http://books.google.com/books?hl=en&lr=&id=ZKYKaznH5PsC&oi=fnd&pg=PA1&dq=Albertsson AC Degradable polymers, recycling, and plasticswaste management &ots=EPwmKJoTmS&sig=Co6u_CLTZzfOae-zMoSZSrxpPwU

Coleman, K., Thorp, L., & Kalpowitz, M. (2009). Understanding energy conservation attitudes, knowledge and behaviors in science laboratories at a tier 1 research-intensive university. *Association for the Advancement of Sustainability in Higher Education*. Retrieved from www.aashe.org/resources/student-research/understanding-energy-conservation-attitudes-knowledge-and-behaviors-science

The College Sustainability Report Card. (2011). *Report Card 2011.* Retrieved from www.greenreportcard.org/report-card-2011/schools

Dahle, M., & Neumayer, E. (2001). Overcoming barriers to campus greening: A survey among higher educational institutions in London, UK. *International Journal of Sustainability in Higher Education, 2*(2), 139-160.

Durham, Z., Kramer, O., Xiang Ong, Z., & Park, S. (2011). Promoting sustainability in campus laboratories: how can University of Michigan promote sustainability and foster environmental stewardship in daily lab practices through technological and behavioral change? Retrieved from http://www.graham.umich.edu/pdf/2011report-labs.pdf

Goodwin, T. E. (2004). An asymptotic approach to the development of a green organic chemistry laboratory. *Journal of Chemical Education, 81*(8), 1187-1190. Retrieved from www.jce.divched.org/hs/Journal/Issues/2004/Aug/clicSubscriber/V81N08/p1187.pdf

Grimm, D. (2007). "This man wants to green your lab." *Science, 318,* 39-41.

Nicolaides, A. (2006). The implementation of environmental management towards sustainable universities and education for sustainable development as an ethical imperative. *International Journal of Sustainability in Higher Education, 7*(4), 414-424. Retrieved from http://dx.doi.org/10.1108/14676370610702217

Rau, E. H., Alaimo, R. J., Ashbrook, P. C., Austin, S. M., Borenstein, N., Evans, … Weaner, L. E. (2000). Minimization and management of wastes from biomedical research. *Environmental Health Perspectives, 108,* 953-977. Retrieved from www.jstor.org.library.unl.edu/stable/4619470

Sherman, J., Chin, B., Huibers, P. D. T., Garcia-Valls, R., & Hatton, T. A. (1998). Solvent Replacement for Green Processing. *Environmental Health Perspectives, 106*, 253-271. Retrieved from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1533296/pdf/envhper00536-0260.pdf

US Environmental Protection Agency. (2012). *Laboratories for the 21st century (Labs21): Home Page.* Retrieved from http://www.labs21century.gov/toolkit/bp_guide.htm

US Environmental Protection Agency. (2011, September 22). *Resource conservation: Common wastes and materials: Plastics*. Retrieved from http://www.epa.gov/osw/conserve/ materials/plastics.htm

Wooliams, J., Lloyd, M., & Spengler, J. D. (2005). The case for sustainable laboratories: First steps at Harvard University. *International Journal of Sustainability in Higher Education, 6*(4), 363-382. Retrieved from http://dx.doi.org/10.1108/14676370510623856

Wright, H. A., Ironside, J. E., & Gwynn-Jones, D. (2008). The current state of sustainability in bioscience laboratories: A statistical examination of a UK tertiary institute. *International Journal of Sustainability in Higher Education, 9*(3), 282-294.

Appendix A - Tables

Table I. Lab Sustainability Checklist			
Does your lab use any of the following methods?	Yes	No	N/A
Energy conservation			
Use/purchase energy efficient or Energy Star™ equipment			
Turn off lights and equipment when not in use			
Turn off fume hoods (or biological safety cabinets) or close sash when not in use			
Minimize use of autoclaves			
Defrost freezers regularly			
Green Chemistry			
Reduce use of chemicals			
Decrease size of experiments to reduce excess chemical waste			
Replace harsh/dangerous solvents with more sustainable solvents			
Use solvent substitution databases to find sustainable solvents			
Participate in chemical reuse programs			
Use Pollution Prevention strategies			
Waste Reduction			
Recycle paper			
Recycle product packaging			
Recycle plastic that is uncontaminated by regulated waste			
Reuse lab materials, such as glass or other containers			
Reduce biological waste by strictly separating biohazard waste from non-biohazard waste			
Sustainable Management			
Sustainable purchasing (buy eco-friendly, recyclable, reusable, post-consumer etc. lab materials when possible)			
Inquire about sustainable products when purchasing			
Sustainable purchasing policy (only buy sustainable lab materials)			
Keep good inventory instead of buying in excess			
Train new lab employees in environmental best practices prior to allowing them to work in the lab			
Require all employees to take environmental best practices training			
Incentives or rewards for maintaining sustainable lab			
Use resources like databases or EPA websites (such as Labs for the 21st Century) to update environmental best practices			
Water Conservation			
Avoid equipment using single-pass cooling			
Only use purified/filtered water when necessary			

Table II. Solvent Substitution Resources	
Resource	**Website**
Coating Alternatives Guide (CAGE)	http://cage.rti.org
Enviroene	http://es.epa.gov
Hazardous Solvent Substitution Data System (HSSDS)	http://es.epa.gov/ssds/hssdstel.html
Integrated Solvent Substitution Data System (ISSDS)	http://es.epa.gov/issds
Joint Service Pollution Prevention (P2) Technical Library	http://enviro.nfesc.navy.mil/p2library
Pacific Northwest Pollution Prevention Resource Center	http://pprc.pnl.gov/pprc
Solvent Alternatives Guide (SAGE)	http://clean.rti.org
Solvents Database (SOLV-DB)	http://solvdb.ncms.org
The Solvent HandbookDatabase System (SHDS)	http://wastenot.inel.gov/shds
Waste Reduction Resource Center	http://www.p2pays.org/wrrc