Staying Green while Being Clean – Green Cleaning and Green Chemistry

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INTRODUCTION

Green chemistry is an emerging trend in industry working to develop environmentally-friendly chemicals and to create fewer hazardous byproducts. This lesson introduces green chemistry, and uses it to look at the science behind green cleaning products. It also discusses Persistent Organic Pollutants, how they are related to cleaning supplies, and the effect they have on the environment.

LESSON OVERVIEW

Grade Level & Subject: 9-12 Science (Health, Chemistry, Environmental Studies).

Length: Two class periods

Objectives:
After completing this lesson, students will be able to:

- Understand the dangers of Persistent Organic Pollutants and the ways in which they get into the environment.
- Be familiar with green chemistry and its 12 principles.
- Use the scientific method to study green cleaning products and green chemistry.

Standards[1]**:**

- **Content Standard: NS.9-12.1 SCIENCE AS INQUIRY**
  As a result of activities in grades 9-12, all students should develop
  - Abilities necessary to do scientific inquiry
  - Understandings about scientific inquiry
- **Content Standard: NS.9-12.2 PHYSICAL SCIENCE**
  As a result of their activities in grades 9-12, all students should develop an understanding of
  - Structure of atoms
  - Structure and properties of matter
  - Chemical reactions
  - Motions and forces
  - Conservation of energy and increase in disorder

[1] Education World (2008). *U.S. National Education Standards*. Retrieved 30 April 2008, from http://www.educationworld.com/standards/national/.

- Interactions of energy and matter

Content Standard: **NS.9-12.6 PERSONAL AND SOCIAL PERSPECTIVES**

As a result of activities in grades 9-12, all students should develop understanding of

- Personal and community health
- Population growth
- Natural resources
- Environmental quality
- Natural and human-induced hazards
- Science and technology in local, national, and global challenges

- **Content Standard:** **NPH-H.9-12.1 HEALTH PROMOTION AND DISEASE PREVENTION**

  Students will comprehend concepts related to health promotion and disease prevention-

  - Analyze how behavior can impact health maintenance and disease prevention.
  - Describe the interrelationships of mental, emotional, social, and physical health throughout adulthood.
  - Explain the impact of personal health behaviors on the functioning of body systems.
  - Analyze how the family, peers, and community influence the health of individuals.
  - Analyze how the environment influences the health of the community.
  - Describe how to delay onset and reduce risks of potential health problems during adulthood.
  - Analyze how public health policies and government regulations influence health promotion and disease prevention.
  - Analyze how the prevention and control of health problems are influenced by research and medical advances.

Materials:

Class One

- Reproducible #1- **Teacher's Guide to Green Cleaning and POPs**
- Reproducible #2- **Green Cleaning Supplies and POP Outline** (1 copy per student)
- Reproducible #3- **The 12 Main Principles of Green Chemistry** (1 copy per student)

Class Two:

- Reproducible #4- **Green Cleaning and Green Chemistry Lab**
- White vinegar
- Baking soda
- Water
- Measuring cups
- Salt
- Pennies (for testing copper cleaner)
- Spray bottles
- Mixing bowls/containers
- Stir sticks or other utensils
- Funnels

- 5 Brand-name cleaning products, such as Windex or Fantastik (these can be brought from home and then returned; only small amounts will be used). Have a cleaning product for each of these areas: tile/countertop, floor, copper, wood, and sink.
- Sponges or other scrubbing materials
- Rubber gloves

Extension:

- **Reproducible #5- Researching the Development of Chemicals** (1 copy per student)

Assessment:

Students will be assessed through the following activities:

- Participation and attentiveness
- Completion of **Reproducible #2- Green Cleaning Lab**
- Optional: Completion of **Reproducible #5- Researching the Development of Chemicals** assignment.

LESSON BACKGROUND

Relevant Vocabulary:

- **Green Chemistry:** Emerging form of chemistry that works to develop environmentally-friendly chemicals and create fewer hazardous byproducts in chemical reactions.
- **Green Cleaning Supplies:** Cleaning supplies that are environmentally friendly and non-hazardous to human or animal health.
- **Persistent Organic Pollutant:** Chemicals that persist in the environment for very long periods of time, bioaccumulate, and pose a risk to human health and the environment. For example, **DDT -** An insecticide introduced in the 1940s and 50s that was thought to be non-harmful to humans. It was banned in the 1970s because it was found to be polluting and accumulating in the environment and all the species within it.
- **Biomagnification:** Concentrations of chemicals increase up the food chain as lower species are eaten and the pollutants are ingested.
- **Control Variable:** The variable that is kept constant and does not change.
- **Dependent Variable:** The variable that is being observed as the independent variable is changed.
- **Independent Variable:** The variable being changed during the experiment.
- **Hypothesis:** An educated guess/proposal based upon research or observations; can be tested by a scientific experiment.

Information:

Every day, houses, schools, and office buildings are cleaned thoroughly to keep people safe and healthy. This is done using a myriad of chemicals, many of which have been synthesized by scientists. However, just because these items are killing bacteria and removing dirt does not necessarily mean they are keeping people safe and healthy. Instead, they often create a new source of danger by introducing chemicals that people interact with and inhale. These chemicals, as well as

others from production of other goods, often spread and persist in even remote environments for years. This is why scientists are currently reconsidering their past methodology to see if they can make safer products.

Resources:

- Basics to green cleaning: http://planetgreen.discovery.com/go-green/green-cleaning/
- Information on POPS: http://www.epa.gov/oia/toxics/pop.htm
- Information on green chemistry: http://www.epa.gov/greenchemistry/
- Biomagnification: http://toxics.usgs.gov/definitions/biomagnification.html

LESSON STEPS

Warm Up: *Evaluating Cleaning Supplies*

1. Have students think about the different types of cleaning supplies that they use at their house. Make a list on the board of each mentioned and all the areas they are used to clean.

2. Using a bottle of cleaning supply as an example, read off the ingredients and ask students how many they have heard of. Have they ever considered what they are being exposed to when they use these supplies in their house?

Activity One: *Connecting Green Cleaning and POPs*

1. Pass out **Reproducible #2- Green Cleaning Supplies and POP Outline** to each student.

2. Using **Reproducible #1- Teacher's Guide to Green Cleaning and POPs**, teach students about green cleaning supplies and POPs, having them fill in their outline and label the diagrams as they go.

3. Leave time at the end for answering questions about the material.

Activity Two: *Finding Solutions- Green Chemistry*

1. Introduce students to the idea of green chemistry (*Green chemistry is defined as the design of chemical products and processes that reduce or eliminate the use and/or generation of hazardous substances. In other words, green chemists not only aim to eliminate hazardous byproducts, but also to minimize or abolish the use of hazardous substances in all processes*). Pass out and go through **Reproducible #4- The 12 Main Principles of Green Chemistry**.

2. Ask students to think about which of the main principles they think are the most important. Are there any that they think are less important then others? Do any not make sense to them?

3. Have students brainstorm and think of areas where green chemistry could be used (*industry, medicine, cleaning supplies, toiletries, paints, etc.*) Write them on the board for everyone to see.

This should help students see that green chemistry affects numerous areas of their lives, and help them to start thinking about how many chemicals they are exposed to each day.

Activity Three: *Green Cleaning and Green Chemistry Lab*

1. ***Before class begins***, set up the five stations where students will compare their cleaner to a brand-name cleaning supply. Each station should be one of the brand-name cleaning supplies mentioned on the table in the lab (i.e. copper, tile/countertop, floor, wood, and sink). You may want to make the area to be cleaned dirtier so that the results from their experiment are easier to observe.

2. Split students into lab groups of 3-4 each.

3. Pass out **Reproducible #4- Green Cleaning and Green Chemistry Lab** to students. Have them collect materials and go over the safety tips before they begin.

Wrap Up: *Peer Review*

1. When they are finished with their lab, explain to students that any scientific study must be published for other scientists to review and critique. This allows opposing viewpoints to be heard and healthy debate to form. Have each lab group discuss what their conclusions were from their experiment. Did everyone else have the same results? What did they observe that was different?

Extension: *The Chemical Revolution*

Use the information in **Reproducible #5- Researching the Development of Chemicals** to have your students write a 1-2 page paper on how chemicals and products originated and why they became mainstream in so many of our daily products. Have them build on this by examining why science and industry are beginning to implement green chemistry practices.

CONCLUSION

At the end of this lesson, students should understand how human activities can impact the environment both negatively and positively. They should exhibit an understanding of the 12 principles of green chemistry. Finally, by creating their own green cleaner and comparing it with brand-name commercial cleaners, the students should comprehend the benefits of green cleaning, and how it relates to a safer and healthier environment.

Teacher's Guide to Green Cleaning and POPs

Green Cleaning

Green Cleaning is using cleaning supplies that do not have a harmful effect on the environment or human health. Often green cleaning can be done using everyday substances at home, saving harmful pollutants from being added to the area. Some examples of green cleaning supplies found at home include vinegar, baking soda, salt, lemon juice, and olive oil.

Persistent Organic Pollutants

"Persistent organic pollutants," or POPs, are chemicals that persist in the environment for very long periods of time, bioaccumulate, and pose a risk to human health and the environment[2]. These can include synthetic (man-made) chemicals, which are often designed to last as long as possible. Plastics, which take over 500 years to biodegrade, are an example of this[3]. One of the biggest problems with persistent chemicals is that they eventually spread to even the most remote regions of the world and then stay there. Infant polar bears in the Arctic ingest our industrial chemicals in their first hours of life through their mother's milk[4]. POPs are found in some cleaning supplies and can be harmful to those who come in contact with them.

DDT: An Example of a POP

In the 1940s and 1950s, the pesticide DDT was wildly popular because of its ability to kill almost any crop-killing, malaria-carrying insect on contact with no apparent negative impact to the humans handling it[5]. It was sprayed liberally by helicopter over enormous stretches of land. Another major benefit of DDT was that it lasted: one spraying could keep a wall insect-free for up to three months[6]. However, critics noticed that birds and other small warm-blooded animals were getting sick and, in some cases, dying. They questioned whether anything so fatal to birds and small mammals could have no negative impacts in the long run. As DDT began to surface increasingly in unexpected places, and bird populations began to decline, scientists and the public began to worry about rather than celebrate its persistence. Eventually it was proven that DDT was preventing successful reproduction in bald eagles and other birds, a fact which called attention to the possibility that DDT might be toxic. In 1972, DDT was banned in the United States.

Biomagnification and POPs

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[2] United Nations Environment Programme. *Persistent Organic Pollutants*. Retrieved 30 April 2008, from http://www.chem.unep.ch/pops.

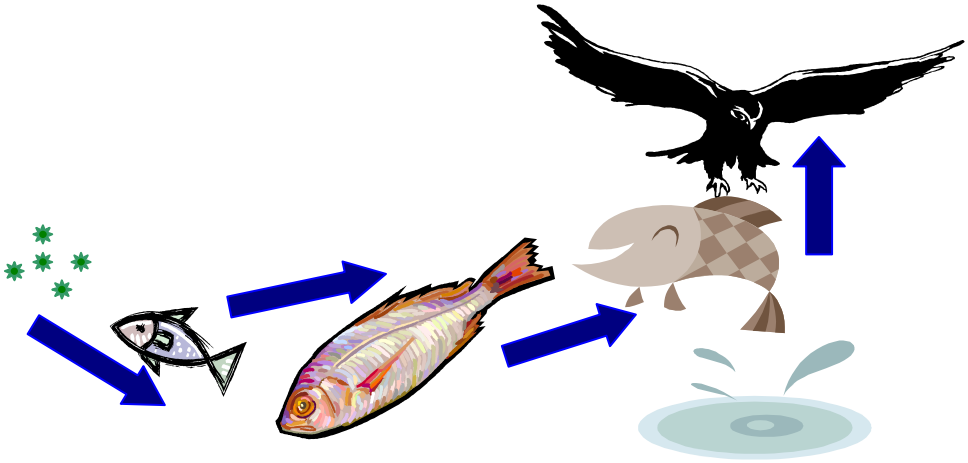
[3] Lapidos, Juliet (2007). Slate. *Will My Plastic Bag Still be here in 2057*. Retrieved 30 April 2008, from http://www.slate.com/id/2169287/nav/navoa.

[4] Cone, Marla (2003) Los Angeles Times. *Poisoning the Polar Bear*. Retrieved 30 April 2008, from http://www.mindfully.org/Heritage/2003/Polar-Bear-Poisoning5jul03.htm.

[5] Davis, Kenneth (1971) American Heritage. *The Deadly Dust: the Unhappy History of DDT*. Retrieved 30 April 2008 from http://www.americanheritage.com/articles/magazine/ah/1971/2/1971_2_44.shtml.

[6] Ibid.

Another major problem with POPs, which played a major part in DDT's negative impact on the bird population, is the phenomenon of biomagnification. Biomagnification occurs when increased concentrations of a chemical are found in organisms higher on the food-chain. A diagram depicting the basic mechanism of biomagnification, with blue arrows indicating the flow of POPS, can be found below:



In this image, a fish consumes plankton that is contaminated with a POP. The chain of consumers passes the POP up the food chain, accumulating higher concentrations in each organism. The higher concentrations occur because higher organisms consume large amounts of the lower organisms that are carriers of a POP. During the height of DDT's use, DDT concentrations were shown to be up to 400 times higher in some birds of prey than in the organisms they directly consumed[7]. This may have been the mechanism that led to the seriously declined reproductive rates of these species during the 1970s[8].

How Else Can POPs Spread?

Now consider other ways in which POPs could spread in the environment. Some examples include[9]:

- Wind patterns moving volatile chemicals (those chemicals that evaporate readily).
- Wind patterns moving POPs that have bound to dust and other fine particles.
- Precipitation containing the POP, which may be moved as clouds by the wind.
- Transportation by the water cycle (rivers, ocean currents, etc.)

These methods of transportation also have other implications. For example, volatile POPs or dust that is contaminated with a POP can make its way into your lungs, affecting respiratory health. In

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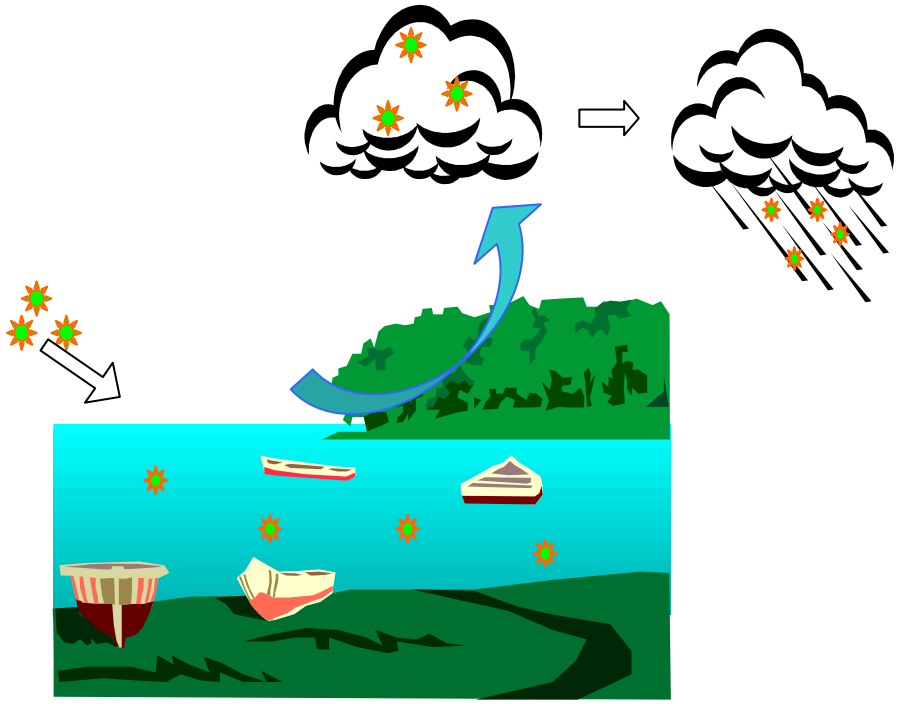
[7] Kimball, John W (2003) *Biomagnification*. Retrieved 30 April 2008 from http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/D/DDTandTrophicLevels.html.

[8] Davis, Kenneth (1971) American Heritage. *The Deadly Dust: the Unhappy History of DDT*. Retrieved 30 April 2008 from http://www.americanheritage.com/articles/magazine/ah/1971/2/1971_2_44.shtml.

[9] CCEA. *Marine Ecozones*. Retrieved 30 April 2008. http://www.ccea.org/ecozones/mar-ab-hum.html.

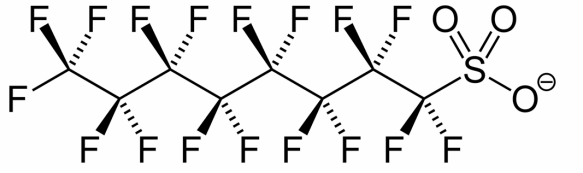
addition, chemicals that come to rest in very cold climates will persist there for many years, often trapped in snow or ice. These chemicals can be absorbed through the skin and stored in tissues. This may be how industrial chemicals came to be found in mother polar bears' breast milk.

The diagram below illustrates the movement of POPs by precipitation:



POPs in Cleaning Products

To illustrate the ways in which green cleaning can prevent the spread of POPs, consider an example of a POP that is in the environment partially as a result of cleaning products. PFOS, or perfluorooctane sulfonate, has been used for cleaning products in addition to a number of other uses, including fire-fighting foams, textiles, paper and packaging, coatings, pesticides, photographic industry, semiconductor, hydraulic fluids, and metal plating[10]. It is also the key ingredient in Scotchgard, a chemical formerly used to make some products stain-resistant. PFOS has been found all over the world, even remote locations totally removed from places where the chemical is produced. This includes everywhere from India to the North Pacific to Alaska to Antarctica. The PFOS molecule looks like this[11]:



[10] Stockholm Convention on Persistent Organic Pollutants (2007) *Persistent Organic Pollutants Review Committee*. Retrieved 30 April 2008 from http://www.pops.int/documents/meetings/poprc/infnote.htm.

[11] *Image: PFOS-2D-skeletal.png* (2007). Retrieved 30 April 2008 from http://commons.wikimedia.org/wiki/Image:PFOS-2D-skeletal.png

Name _____ Date _____

Green Cleaning Supplies and POP Outline

I. Green Cleaning

1. Definition:

2. Examples:

II. Persistent Organic Pollutants

1. Definition:

2. Problems:

III. DDT

1. Origins:

2. Popularity:

3. Problems Discovered:

4. Results:

IV. Biomagnification:

1. Definition:

2. How POPs are involved:

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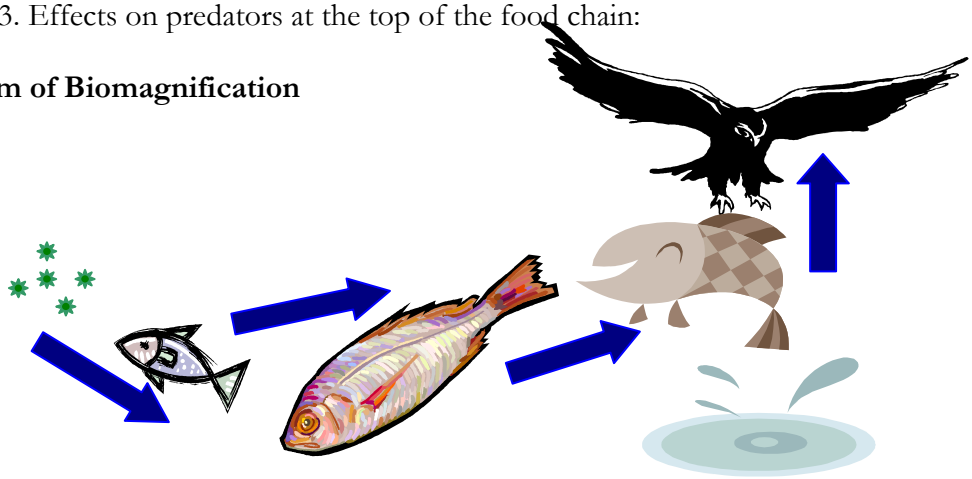
3. Effects on predators at the top of the food chain:

Diagram of Biomagnification



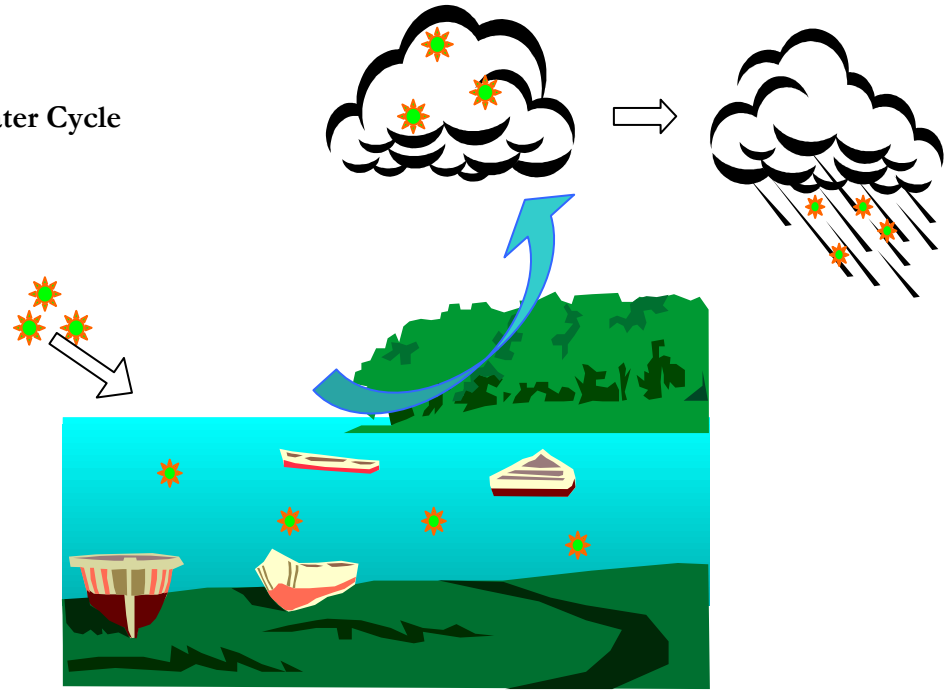
V. Spreading POPs

1. Wind Patterns:

2. Water Cycle:

3. Health Implications:

POPs in the Water Cycle



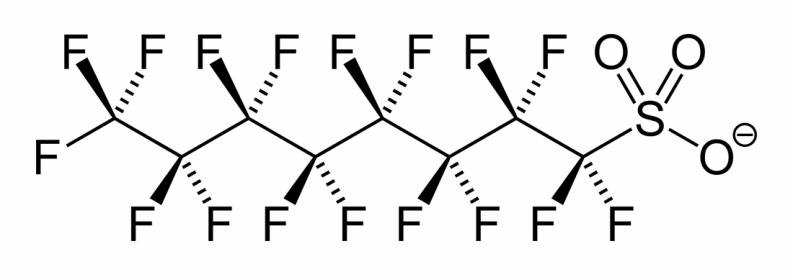
VI. Cleaning Products and POPs

1. Example- perfluorooctane sulfonate (PFOS):

2. Uses:

3. Where it's found:

Diagram of a PFOS Molecule



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The 12 Main Principles of Green Chemistry

Green chemistry has 12 principles main principles. Those principles as defined by the EPA are[12]:

1. **Prevent waste:** Design chemical processes that prevent the creation of waste, so there is less to clean up and dispose of.
2. **Design safer chemicals and products:** Design chemical products to be fully effective, yet have little or no toxicity.
3. **Design less hazardous chemical syntheses:** Design processes to use and generate substances with little or no toxicity to humans and the environment.
4. **Use renewable feedstocks:** Start production with materials that are renewable. They can be agricultural products or the wastes of other processes. Nonrenewable materials are derived from petroleum or other fossil fuels.
5. **Use catalysts, not stoichiometric reagents:** Minimize waste by using small amounts of "catalysts," which speed up reactions or make them more efficient. Large amounts of "Stoichiometric reagents" are more complicated and much less efficient.
6. **Avoid chemical derivatives:** Derivatives use additional reagents and generate waste.
7. **Maximize atom economy:** Design syntheses so that the final product contains the maximum proportion of the starting materials. There should be few, if any, wasted atoms.
8. **Use safer solvents and reaction conditions:** Avoid using extra chemicals, such as solvents, but if they are necessary then make sure they are harmless.
9. **Increase energy efficiency:** Run chemical reactions at room temperature and pressure whenever possible.
10. **Design chemicals and products to degrade after use:** Design chemical products to break down to harmless substances after use so that they do not accumulate in the environment.
11. **Analyze in real time to prevent pollution:** Include in-process real-time monitoring and control to minimize or eliminate the formation of byproducts, which are wasteful and potentially harmful.
12. **Minimize the potential for accidents:** Design chemicals and their forms (solid, liquid, or gas) to minimize the potential for chemical accidents including explosions, fires, and releases to the environment.

Following these guidelines, green chemists hope to break the perception of chemistry as a way to get from A to B as easily as possible, and instead use it as a way to create the things we need in a sustainable way.

[12] US EPA (1998) *Green Chemistry*. Retrieved 30 April 2008 from http://www.epa.gov/greenchemistry/pubs/principles.html.

Name: _____
Date: _____

Green Cleaning and Green Chemistry Lab

You are going to be a green chemist for a day! Green chemists work to replace dangerous chemicals with chemicals that are safe and environmentally-friendly. The goal of this project is to mix your own green cleaning product, and use the scientific method to test how effective it is compared to more common products.

Materials:

- White vinegar
- Baking soda
- Water
- Measuring cups
- Salt
- Pennies (for testing copper cleaner)
- Mixing bowls/containers
- Stir stick or other utensil
- Funnels
- Spray bottles
- Brand-name cleaning products, such as Windex or Fantastik
- Sponges or other scrubbing materials
- Rubber gloves

Safety tips:

- Keep the baking soda well away from the vinegar!
- Open the windows if possible or turn on fans to keep the room well ventilated
- Make sure the students protect their hands with gloves

Instructions:

1. Start by putting on gloves to protect your hands.

2. There are 5 different stations set up around the room with one brand-name cleaner at each station. Each station represents one of these areas: floor, wood, copper, glass, and tile/countertop. You will have to test your cleaner against the name brand cleaner at each station and compare the differences. Using the chart below as a guide, decide how you want to make your green cleaning product. You may follow a recipe exactly as below, combine some of them, or create your own. Be sure to record exactly how much of each product you use, pour it into the mixing bowl and stir as needed.

Product	Sample Brand Name	Green Cleaner Recipe[13]
Tile/counter cleaner	Fantastik	Combine baking soda and water to form a paste. Scrub onto surface and rinse well with water to prevent leaving a film.
Glass cleaner	Windex	Add one quarter cup of white vinegar to two cups water. Use in a spray bottle if one is available, and wipe off with paper towels.
Copper cleaner	Sur La Table	Take equal amounts of vinegar and salt (starting with very small amounts) and dissolve the salt into the vinegar. Dip in a cloth and rub it on the surface, and rinse well with water afterward.
Wood polish	Pledge	Dissolve one teaspoon olive oil in one half cup white vinegar, rub onto surface with a soft cloth, and polish with a dry cloth.
Floor cleaner	Clorox Disinfecting Floor Cleaner	One tablespoon of white vinegar in 16 ounces of water. The vinegar smell fades away soon after the floor dries.

3. Once your cleaning product is complete, pour it into the spray bottle by using the funnel.

4. Record the name of your cleaning product and the ingredients you used in it:
   Our cleaning product is called _____.
   It consists of these ingredients: _____
   _____
   _____.

5. In the chart below, make a **Hypothesis** about your cleaning product and how it will compare with each of the various brand-name cleaners.

6. **Test your hypothesis** at each station by using the brand-name product on one patch (be sure to follow the directions on the bottle!) and your green product (using your teacher's

[13] King County Public Health (2007) *Green Cleaning Methods*. Retrieved 30 April 2008 from http://www.metrokc.gov/health/asthma/facts/greencleaning.htm.
AND
The Green Guide. *Good, Clean Fun*. Retrieved 30 April 2008 from http://www.grist.org/advice/possessions/2003/03/18/possessions-cleaning/index.html.

instructions) on the other. Make sure to leave a patch untouched to be used as your control variable.

7. What **observations** do you have about the products? Record your observations in the table below. Include things such as smell of the cleaners, whether they clean the area, difficulty of use, etc.

Station	Hypothesis	Control Area Observations	Your Green Cleaner Observations	Brand-Name Cleaner Observations
Floor				
Copper				
Tile/ counter-top				
Wood				

Sink				

8. **Analyze your data** and record any trends and patterns that you notice (or lack thereof). What stuck out to you? Did any of your results surprise you?

_____
_____
_____
_____

9. **Draw conclusions** from the observations and data you have collected. Was your hypothesis supported or refuted? Why, or why not?

_____
_____
_____
_____
_____
_____

Reflection Questions

1. What were the control, dependent, and independent variables in this experiment?
   Control: _____
   Dependent: _____
   Independent: _____

2. What could have led to skewed or biased results in your experiment? How would you fix the experiment so that this did not occur?

_____
_____
_____
_____

3. Has this experiment changed your mind about green cleaning products at all? Would you consider using them in your home?

_____
_____
_____

4. How can chemists use green chemistry to make cleaning supplies safer? Look on the back of some of the name brand cleaning supplies you used. Are there any ingredients that you don't recognize or that seem harmful to you?

_____
_____
_____
_____
_____

5. How does using green chemistry help the environment and those species living within it?

_____
_____
_____
_____
_____

6. Draw a diagram explaining how persistent organic pollutants in a cleaner could eventually end up in a top predator, such as a hawk.

Extension Activity- Researching the Development of Chemicals

An enormous rise in the development and use of synthetic chemicals occurred around World War II. This was known as the second "chemical revolution." During this time, scientists worked to develop new products that were more efficient to use or produce than the old ones. In many cases, however, the environmental impacts of these products were not considered. One example is DDT, which was patented in 1940. Another example is the development of synthetic detergents. For example, propylene tetramer benzene sulphonate was enormously popular until the 1960s, when it was revealed to be the source of arising sewage problems[14]. In this way it was discovered that propylene tetramer benzene sulphonate was not biodegradable, and therefore a poor choice for the environment. Despite these and other warning signals about the environment and synthetic chemicals, more and more continued to be produced. At the end of World War II, the market was swamped with synthetic chemicals. Even carboxymethylcellulose, which had been in the industry for many years, only began to be mass-produced during this time period. The chart below indicates the enormous rise of these chemicals in common use during this time period:

US Soap and Detergent Sales[15]

Year	Soap Sales 1000 tons	Synthetic sales 1000 tons
1940	1410	4.5
1950	1340	655
1960	583	1645
1972	587	4448

To examine the influence of the "chemical revolution" on cleaning products, have the students research a common household detergent or cleaner, such as Tide, and use the information to complete the assignment below.

Assignment: Thoroughly research the development of this product. Use the information you collect to answer the following questions in a 1-2 page paper.

- What is this product used for?
- Did it replace another product in society, or create a new niche? If the former, how is this product different?
- When was it created? By whom? What's the story here (was it an accident or what)?
- Does it have any environmental impacts you can find? For example, is it biodegradable or does it persist? (Tip: try looking up the Material Safety Data Sheet of the product)

[14] Kiwi Web. *Development of the Detergent Industry*. Retrieved 30 April 2008 from http://www.chemistry.co.nz/deterghistory.htm.
[15] Ibid.

- Keeping environmental factors in mind, do you think this product is more beneficial or more harmful to society? Why?