Teacher Background Information

The 12 Principles of Green Chemistry

1. Pollution Prevention

This principle is the most obvious. It goes back to the old adage "an ounce of prevention is worth a pound of cure". It is better to prevent waste than clean it up after-the-fact. Throughout history there were many cases of environmental disasters that demonstrated this (Bhopal, India; Love Canal; Times Beach; Cuyahoga River).

2. Atom Economy

This principle gets more into the actual chemistry of how products are made. As chemists, atoms are assembled to make molecules. The molecules are assembled together to make materials. This principle says that it is best to use all the atoms in a process. And, those atoms that are not used end up as waste. The atom economy is a simple calculation that can be used when teaching stoichiometry and chemical reactions. The calculation is: A.E. = Formula Weight (FW) of Product divided by the FW of all of the reactants. It is a simple measure of the amount of waste in a process.

3. Less Hazardous Chemical Synthesis

This principle is aimed at reducing the hazard of the chemicals that are used to make a product. Throughout the history of how we have invented products and developed the process for making them, chemists have traditionally not thought about what reagents they are using and the hazards that are associated with them. Chemists have traditionally used whatever means necessary. Today we are finding that less hazardous reagents and chemicals can be used in a process to make products… and, many times they are made in a more efficient manner!

4. Designing Safer Chemicals

The previous principle was focused on the process. This principle focuses on the product that is made. Everyone wants safe products and efficacious. We can design safer chemical products that do what they are supposed to do, but have reduced toxicity. A good example of this is pesticides; which are products that are designed to be toxic. Many researchers are focused on created pesticides that are highly specific to the pest organism, but non-toxic to the surrounding wildlife and ecosystems.

5. Safer Solvents and Auxiliaries

Many chemical reactions are done in a solvent. And, traditionally organic solvents have been used that pose hazards and many are highly toxic. They also created volatile organic compounds (VOC's) which add to pollution and can be highly hazardous to humans. This principle focuses on creating products in such a way so that they use less hazardous solvents (such as water). A good example of this is nail salons. Have you walked by them and caught a smell of the solvents that are used? The solvents that are used in salons can pose a hazard to humans. Many researchers are focused on creating products, such as nail polish, that will not have the solvents in them. For example, a completely water-based polish would avoid the exposure that goes along with the nail products and reduce the hazards associated with it.

6. Design for Energy Efficiency

Today there is a focus on renewable energy and energy conservation. This principle focuses on creating products in a highly efficient manner and reducing the energy associated with creating products.

7. Use of Renewable Feedstocks

90-95% of the products we use in our everyday lives are made from petroleum. Our society not only depends on petroleum for transportation and energy, but also for making products. This principle seeks to shift our dependence on petroleum and to make products from renewable materials that can be gathered or harvested locally. Biodiesel is one example of this where researchers are trying to find alternative fuels which can be used for transportation. Another example is alternative, bio-based plastics (plastics are made from petroleum also). PLA (polylactic acid) is one plastic that is being made from renewable feedstocks such as corn and potato waste.

8. Reduce Derivatives

This principle is perhaps the most abstract principle for a non-chemist. The methods that chemists use to make products are sometimes highly sophisticated. And, many involve the manipulation of molecules in order to shape the molecules into what we want them to look like. This principle aims to simplify that process and to look at natural systems in order to design products in a simplified manner.

9. Catalysis

In a chemical process catalysts are used in order to reduce energy requirements and to make reactions happen more efficiently (and many times quicker). Another benefit of using a catalyst is that generally small amounts are required to have an effect. And, if the catalyst is truly a "green" catalyst it will have little to no toxicity and it will be able to be used over-and-over again in the process.

10. *Design for Degradation*

Not only do we want materials and products to come from renewable resources, but we would also like them to not persist in the environment. There is no question that many products we use in our daily lives are far too persistent. This principle seeks to design products in such a way that they perform their intended function and then, when appropriate, they will degrade into safe, innocuous by-products when they are disposed of.

11. *Real-time Analysis for Pollution Prevention*

Imagine if you have never baked a cake before in your life. You mix the ingredients; you place the cake in the oven. But, for how long do you cook it and at what temperature? How will you know when the cake is done? What happens if you cook it too long or for not enough time? This process is similar to what chemists have to do when they make products. How long do they allow the reaction to run for? When do they know it will be "done"? If there was a way to see inside the reaction and to know exactly when it would be done, then this would reduce waste in the process and ensure that your product is "done" and is the right product that you intended to make.

12. *Inherently Safer Chemistry for Accident Prevention*

This principle focuses on safety for the worker. It is better to use materials and chemicals that will not explode, light on fire, ignite in air, etc. when making a product. There are many examples where safe chemicals were not used and the result was disaster. A recent example is that in Danvers, Massachusetts where a company had an explosion that resulted in many homes surrounding the plant being destroyed; luckily there were no deaths and very few injuries. But, the type of chemicals that poses these hazards should be avoided to minimize accidents.

Analogies to use with your students:

Here is a list of analogies that teachers and students have come up with to help put the 12 principles in a way that everyone will understand them. Please let us know if you have one to add.

#1 It is better to put your clothes in the laundry hamper as you take them off than having them accumulate on your floor until you can't open the door of your room and your mom yells at you.

#8 For years, chemists have worked on trying to get molecules to do things that they want them to do and to become things that they have to force them to become. In green chemistry we take into account what the molecule is predisposed to be and how it wants to behave. It is like molecular career counseling.

#9 Green catalysts are like bicycle stands. You need one to assemble a bicycle and then once the bicycle is made you can remove it and assemble another one. If the stand were made out of wood it would also be renewable which is the best kind of catalyst.

#11 Real-time analyses is like when you are cooking a meal and it is something you have never tried before, you can't just walk away from it. You have to be constantly checking to see if the food is cooked and checking to make sure it tastes right. Scientists also need to be monitoring their processes constantly to make sure that they are getting the product that they want in the way that they want and using the other principles to assess these things.

Teacher Cheat Sheet

1. Create no waste
2. Nothing should be left over
3. No toxicity
4. Green products have to work as well as non-green products
5. Get rid of all non-essential additives
6. Reduce energy usage
7. Use renewable materials
8. Get rid of as many steps as possible
9. Make use of a reusable method to speed up a reaction
10. Use materials that break down in the environment (Biodegradable)
11. Check everything you do against the other principles
12. Safety first