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Green Chemistry: The Future Is in Your Hands

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by Stephen J. Griffith

> The historian of science may be tempted to exclaim that when paradigms change, the world itself changes with them. Led by a new paradigm, scientists adopt new instruments and look in new places. Even more important, during revolutions scientists adopt new instruments and look in new places. [1]

Introduction

As educators, it is imperative to teach students the fundamentals and concepts of what we are directed to teach. It is also extremely important to be able to teach students what the context of what they are learning has on their daily lives in the present and in their future. The basic understanding of chemistry and the role it plays is an essential part of middle school education. This understanding helps better prepare students for the rigors of high school chemistry and also provides an understanding of how the natural world operates in relation to that of the synthetic world of the chemist. It is with these thoughts of basic chemistry that this unit unfolds before you as it encompasses an understanding of what students already are familiar with while also providing them with the understanding of some new principles that will change the course of chemistry forever.

Green Chemistry brings about a fundamental difference in how the chemical process is treated. It is the cutting edge of the chemical industry today and can fundamentally change our lives for the better in the future by assessing environmental concerns today. Once one understands the twelve principles of Green Chemistry that have been established it becomes painfully obvious how this form of chemical synthesis should have been established for many years. Based on the roles of normal science and how science evolves over time, Green Chemistry, relates to why change in science can sometimes take so long, while other times can seem explosive. [2] Chemistry as it is practiced today has changed little with the processes used over one hundred years ago. The Green Chemistry approach is changing how the chemical industry creates new products for use and is slowly creating a revolution in the industry that will forever change how chemistry is practiced. [3] This will be achieved when it is embraced universally by chemists and consumers everywhere.

It is due to the nature of what Green Chemistry has to offer that it becomes vital for students of this day and age to know, understand, and practice the principles of Green Chemistry in their daily lives so they become the first of a full generation to practice this concept. [4] This is not designed to make them future chemists; it is designed with the dogmatic approach to teach them these new concepts so they may be aware of better use and practice of chemistry in the real world so they may become outspoken advocates of the movement in their future.

The following unit is designed to take existing form of chemistry education and expand upon it by including this revolutionary new approach. The target audience for this is an 8 th grade science classroom. It is intended to be used during the instruction of basic chemistry as an extension to the curriculum guidelines already established. By following this plan, the students in my class will achieve all of the state standards of Georgia (see appendix) while also teaching a new and exciting subject that has yet to become part of the standards. The unit should be integrated into the daily rituals of learning basic chemistry; the subject matter will be used in pieces over a four to five week period before finally culminating in a student project that will be done independent of class time.

Overview

> "Such prosperity as we have known it up to the present is the consequence of rapidly spending the planet's irreplaceable capital"
>
> Aldous Huxley (1894 -1963)

By promoting life-changing concepts for these students to practice, it becomes important to first understand the past, and what chemical synthesis has created and what it has developed into today. The most important objective of all synthesis is to gain a new product, one that is more desirable to your lifestyle and the culture that you live in. To understand the history of synthesis, students will be engaged in a learning of the ancient world and how some early metallurgy evolved into the first aspects of chemical synthesis. This early history will show how ancient people first developed the use of smelting naturally occurring ores for use in making better tools, and military instruments, as well as in creating dyes for cloth and glazes for pottery that help make pottery stronger. All of these ancient devices were the first aspects of using chemical synthesis although in a haphazard way as there was no periodic table or knowledge of what objects could blend well together.

It is due to this first accidental aspect of chemical synthesis that we have arrived in a world filled with environmental problems that we have today. These cultures only knew what materials would mix with each other to make new substances; they were not aware of what waste products they were also creating in the process, or if they were, it was not a potential problem as they still acquired the substance that was initially sought after. This created generations only looking at what they were able to create without regard to what was left behind. This internal philosophy of creating new substances with disregard has continued through the modern day. The remainder of ancient history will look at the Greek and Roman cultures, and the rise of alchemy as the predecessor to modern chemistry. [5]

The late eighteenth and early nineteenth centuries mark a point on the chemistry timeline where students can fundamentally see what chemical synthesis is. With the creation of the periodic table and an understanding of chemical properties came about the science of stoichiometry which shows two or more reactants being combined through chemical means to create one or more products. Once one knows what they want to create, they can work backwards to understand what objects in nature they can obtain for the creation of the new substance. Through a thorough analysis of stoichiometry, students will understand the different chemical processes and how to balance an equation out. Through the use of the understanding of the measurement of a mole, students will be able to predict how much of different elements are needed to generate whatever new substance they desire. This will be beneficial in the ultimate understanding of Green Chemistry.

The 20 th Century marks a point in history essential to understanding the environmental effects that have occurred due to past chemical processes. The advent of chemical warfare through the first and second world wars as well as the explosive use of chemical pesticides demonstrates the need for a solution. The original solution to the problem was to get rid of the extremely toxic chemicals. This was brought on by the environmental movement that Rachel Carson and Silent Spring had a lot of help in creating and increasing the public's awareness of the problem of chemicals in the environment. Although written in an apocalyptic style, it had the result of helping to formulate new legislation for the chemical industry, thus helping the environment overall. The impact of the environmental movement did not, however, change the practice of all of the chemical industry. Many companies continued their practices of creating as much product as possible without care or conviction to the amount of by-product or waste that was also resultant from their chemical practices. This ultimately ends in the eventual learning and use of the principles of green chemistry as demonstrated in Paul Anastas' book, Green Chemistry Theory and Practice. Once one understands the principles and practices of this new approach to chemistry it becomes evident how the chemical industry should embrace this form of chemical practice as a way of not only helping the environment, but also at increasing their profitability in the market place.

Green Chemistry: A Basic Understanding

> "Pollution is nothing but the resources we are not harvesting. We allow them to disperse because we've been ignorant to their value"
>
> R. Buckminster Fuller (1895 - 1983)

Green chemistry is a new approach to an old science. It is taking what we already know about chemistry and how to form new substances and redesigning that method to be both more economical and also better for the environment by preventing pollution and containment problems. It is essentially finding a better approach for this method. Paul Anastas writes that in 1994 there were 2.26 billion pounds of the approximately 300+ hazardous substances released into the environment. Of that most of these hazardous substances come directly from the chemical industry and not the end user of a final product. [6] Most end-user or consumer products have already been reduced of their potentially high levels of toxicity to the environment through the legislative acts of the environmental movement. Synthetic chemists play a central role in developing green chemical methods for pollution prevention and as a result the end-user benefits from products being made in ways to better help the environment. [7] Through public awareness of this problem and solution to the problem, the environment and chemical practice around the world will adapt to this new approach

What remains still to this day are a large number of waste products generated by the chemical industry as a result of low yield synthesis in their production of obtainable marketable products. [8] A lot of this comes from the use of petroleum, and petroleum constituents, as the base feed stock (the main additive component of any chemical reaction) for many of these procedures. [9] This low yield results in a large number of waste products not intended for resale and, thus, are dumped or burned resulting in potential ecological disasters. Due to modern awareness of the damaging effects humans have on the environment, strategies have been implemented to streamline this new approach to chemistry so that it might be embraced by an industry slow to change. This is a modern day scientific revolution unfolding that will forever change human practice of a generation of new synthetic compounds. [10] A list of the twelve principles of green chemistry for the industry is found in the appendix.

The proper execution of these principles will result in a newly established approach to chemical synthesis. To understand the twelve principles in full, please see teacher appendix for the list of principles. So what does this list mean in layman's terms and how can these principles be applied into education. The latter of this statement will be derived in the section under strategies. Since this is such a new science, this section shall be devoted to a basic understanding of the knowledge so as to apply it properly in a classroom situation.

If we look at a common chemical synthesis, we can break down the differences between traditional chemistry and that of green chemistry. The equation for photosynthesis is $6\ CO_2 + 6\ H_2O \rightarrow C_6H_{12}O_6 + 6\ O_2$ with the understanding that light energy is required to start the reaction causing the oxidation of the water molecules and reduction of carbon dioxide. When one looks at this equation, it can be understood that there are two reactants being combined (carbon dioxide and water) and reformulated to become two products (glucose and molecular oxygen). The beauty of the equation though is that there is essentially no waste. This is not because the plant needs the oxygen that is released; instead the oxygen is being utilized by animals and, thus, is reclaimed as opposed to becoming waste. The glucose that is created ($C_6H_{12}O_6$) and maintained in the plant is essential for animal survival as it is used in cellular respiration. The oxygen that is generated becomes atmospheric oxygen which is also used by the animal kingdom. The result of this is a true green reaction in that there are no waste by-products being generated, as the waste oxygen has been reclaimed elsewhere. The resulting products of cellular respiration (carbon dioxide and water) are the reactants needed for the photosynthesis side of the equation to begin again, making the process a continuous cycle. This is the major goal and aim of green chemistry in creating a sustainable system with minimal waste and ideally no waste.

Unfortunately chemistry for the most part does not create new products so easily. Instead what normally happens is the creation of the product with a lot of matter that is not needed and, therefore, wastes. To illustrate this idea, the pharmaceutical company represents a great opportunity. This industry is driven by the profitability of the end result product, not the amount of waste generated during the process. Often the product is in ratio to its waste anywhere in order of magnitude of 1 part product to 25 (and up to 100) parts of waste by-product. This is to say that for every 1 gram of useful pharmaceutical product being utilized by a consumer there is anywhere from 25 to 100 grams of waste being discarded by the pharmaceutical company. Ibuprofen, which has been around since 1969, is a great example to illustrate how the chemical industry had synthesized a product one way unchanged for many years, producing massive amounts of waste. Yet when they focused on another route, they were able to synthesize the same product with much less waste. To illustrate the idea, we will disseminate through the history of ibuprofen through its original synthesis and the modern synthesis being used today. [11]

The Boots Company Synthesis of Ibuprofen

Ibuprofen is the active ingredient in a number of brand name products including Advil, Motrin and Nuprin. Ibuprofen acts as an analgesic (pain reliever) and is also

effective as a Non-Steroidal Anti-Inflammatory Drug. The world production of ibuprofen exceeds 30 million pounds per year. The Boots Company PLC of Nottingham,

England first patented the synthesis of ibuprofen in the 1960's (U.S. Patent 3,385,886) which served as the main method of synthesis for many years. The Boot's synthesis of ibuprofen is a six-step synthesis with much waste being generated. When this process was first created and patented it was the usefulness of the end product that made it worthwhile without worry to how much waste was generated (this is similar to many chemical process and routines, making it an essential understanding of Green Chemistry). If you look at table 1, you can see the characteristics in each step of the process. For further clarification of this process, please go to teacher appendix that includes a link to see the visual model for use as an aid during class instruction. [1] [2]

Atoms of each reagent that are incorporated into the final desired product (ibuprofen) are shown in center column and those that end up in unwanted products are shown in the last column to right. Table 1 illustrates the atom economy of the Boots Company synthesis and allows one to calculate an atom economy of 40% (atom economy will be further defined under the heading strategies). As was indicated above, about 30 million pounds of ibuprofen are manufactured on a yearly basis. If the entire world's supply of ibuprofen were manufactured by the Boots process, then this would generate about 35 million pounds of waste! [1] [3]

TABLE 1 Atom Economy of the Boots Company Synthesis of Ibuprofen

Reagents Formula	Reagents FW	Utilized Atoms	Weight of Utilized Atoms	Unutilized Atoms	Weight of Unutilized Atoms
1 $C_{10}H_{14}$	134	10C,13H	133	H	1
2 $C_4H_6O_3$	102	2C,3H	27	2C,3H,3O	75
4 $C_4H_7ClO_2$	122.5	C,H	13	3C,6H,Cl,2O	109.5
5 C_2H_5ONa	68	___	0	2C,5H,O,Na	68
7 H_3O	19	___	0	3H,O	19
9 NH_3O	33	___	0	3H,N,O	33
12 H_4O_2	36	H,2O	33	3H	3
Total 20C,42H,N,10O, Cl,Na	514.5	Ibuprofen 13C,18H,2O	Ibuprofen 206	Waste Products 7C,24H,N,8O, Cl,Na	Waste Products 308.5

% Atom Economy = (FW of atoms utilized/FW of all reactants) X 100
= (206/514.5) X 100 = 40%

The BHC Company Synthesis of Ibuprofen

In the eighties, ibuprofen was approved for over-the-counter use and the Boots Company patent expired. Recognizing the financial opportunities that the manufacture and sales of this drug could offer, several companies embarked upon setting up facilities and developing new methods for the preparation of ibuprofen. Due to competition in the marketplace to make a cheaper product, it was pertinent to develop a more stream-lined approach to synthesizing ibuprofen. The Hoechst Celanese Corporation discovered a new three-step synthesis of ibuprofen. Together with the Boots Company, they formed the BHC Company to prepare (by this new synthesis) and market ibuprofen. The BHC Company synthesis is show below in Table 2 with the utilized atoms in center column and the unutilized atoms in the final column. The atom economy is further illustrated in Table 2 and calculation of the % atom economy gives 77%, a significant improvement over the 40% of the original process. [14] This new process not only stream-lined the synthesis by reducing the number of steps, it also greatly reduced the amount of waste being generated. This is the key to Green Chemistry in that the identical final substance was created, yet it took less energy, and produced less waste making the entire process both more profitable to the company but also more beneficial to the environment.

Table 2 Atom Economy of the BHC Company Synthesis of Ibuprofen

Reagents Formula	Reagents FW	Utilized Atoms	Weight of Utilized Atoms	Unutilized Atoms	Weight of Unutilized Atoms
1 $C_{10}H_{14}$	134	10C,13H	133	H	1
2 $C_4H_6O_3$	102	2C,3H,O	43	2C,3H,2O	59
4 H_2	2	2H	2	___	0
6 CO	28	CO	28	___	0
Total 15C,22H,4O	266	Ibuprofen 13C,18H,2O	206	Waste Products 2C,4H,2O	60

% Atom Economy = (FW of atoms utilized/FW of all reactants) X 100
= (206/266) X 100 = 77%

The atom economy of the BHC Company process jumps to ~99% if one considers that the acetic acid generated in Step 1 is recovered and reused.

Not only does the BHC Company process offer a dramatic improvement in the atom economy, it offers other environmental advantages. These include a three-step catalytic process vs. the six-step Boots Company process that requires auxiliary reagents in stoichiometric amounts. For example, the first step in each process yields the same product from the same reactants. However, the Boots Company process utilizes aluminum trichloride in stoichiometric amounts while the BHC Company process uses HF in catalytic amounts that is recovered and reused repeatedly. The aluminum trichloride produces large amounts of aluminum trichloride hydrate as a waste product which is generally land-filled. The nickel and palladium catalysts used in Steps 2 and 3 of the BHC Company process are also recovered and reused. [15]

Because the BHC Company process is only three steps (vs. six steps for the Boots Company process) and it has a much improved atom economy, it not only results in a dramatic decrease in the waste produced, it also allows for a greater profit margin (more ibuprofen in less time and with less equipment). These factors translate into economic benefits for the company as a result of the fact that less money is required to deal with the waste that is generated and less capital expenditure is required to produce the same amount of ibuprofen. Thus, not only does the environment benefit, but the company's bottom line is strengthened and good public relations can be reaped as a result of a greener process. [16]

One should recognize that you do not have to be an expert in chemistry, or understand each phase of the production to see the importance and relevance of the two separate processes. Instead, it is important to recognize the number of step and be able to see the waste products produced in each step vs. the amount of actual desired product by the end of the set of reactions. The ideas encompassed in the illustration of ibuprofen show the main principle behind the green chemistry movement. This is based on the principle of the atom economy. This concept states that reactions for environmental and economic reasons should be designed for efficiency. The atom efficiency looks at all of the products that are generated and bases their value on what products are actually desired vs. the total of all chemicals used in the process. A simpler example for illustration is that of the production of propene which will be further discussed in the section on strategies (a detailed understanding of propene manufacture can be found using a URL found in the teacher appendix). Once this is understood the process behind the synthesis of ibuprofen becomes clearer. The products that are not desired are considered waste; this is what the chemical industry for generations has created a lot of just to get a small yield of the desired product. By looking at alternative feedstock, catalysts, and solvents for use in chemical reactions, chemists are finding new ways to generate the same products with less waste associated with it.

For a better understanding of green chemistry, it is suggested that you read the book Green Chemistry: Theory and Practice by Paul Anastas and John Warner. This book is written in easy to understand terms for people who are not specialized in chemistry yet want to understand the process and principles behind green chemistry.

Prerequisite Knowledge

> "The world can only be grasped by action not by contemplation. The hand is the cutting edge of the mind"
>
> Jacob Bronowski (1908-1974)

In order for this unit to be a success and beneficial for students, it must be understood that a certain amount of prerequisite knowledge must be obtained either before the start of this unit or simultaneously with this unit. With that understood, this section outlines the basic understandings students should be aware of and be able to practice concepts of before beginning. Otherwise the information on green chemistry is only information, and not practical knowledge that can then be put into practice by your students.

Students should have a firm understanding of the basic units of an atom and how they operate. They should know that the electron (e-) has minimal mass, but most of the volume of an atom and has a negative electrical charge. They should also know that the proton (p+) is in the nucleus with a positive charge and coupled with the neutron (n) of neutral charge they make up the majority of the mass of the atom but very little of the volume. Students should be able to use and utilize the periodic table, understanding the difference between the vertical groups or families and how they have similar chemical properties to the horizontal periods that have increasing number of electrons in their valence shell or energy level. Students should be most familiar with elements 1 through 20 and the basic properties of said atoms. They should understand the difference between atomic number and the atomic mass of an element. With said knowledge, they should be able to determine with speed and efficiency the number of e-, p+, and n of any given atom. Through this information, students should also be presented with the identification and understanding of isotopes and how certain atoms can have more or less n found in the nucleus, thus changing the properties of the atom. From this basic understanding of isotopes, students should be presented with radioactive decay in order to understand how certain elements behave in nature by decaying to other chemical forms.

With this basic information, students should be given time to understand the principles behind the valence shell of an atom and the maximum number of 8 e- to be found in that area. With that information, students can harvest information about both covalent bonding (the sharing of e-) and ionic bonding (the giving up or taking of extra e- with the understanding of the names of the cation and anion). With students gaining the ability to understand the bonding of atoms, they are able to solidify that information through chemical equations and the ideas based on stoichiometry. Stoichiometry is the branch of chemistry that deals with the application of the laws of definite proportions and of the conservation of mass and energy to chemical activity. This process should also have a component of the understanding of what a mole is and how it can be used in obtaining information about chemical formulations and the amount of materials used in the equation as compared to the amount of materials that result from the synthesis. Students should understand the types of chemical reactions and formations that can take place such as:

Synthesis is the reaction of 2 or more elements to form a compound.

General formula A + B → C

Example

$4\ Fe + 3\ O_2 \rightarrow 2\ Fe_2O_3$

Decomposition is the breaking down of a large molecule into its elements or into smaller substances.

General formula C → A + B

Example

$2\ KClO_3 \rightarrow 2\ KCl + 3\ O_2$

Single replacement is when 1 element reacts with a compound to form a new compound.

General formula x + yA → xA + y

Example

$Cu + 2\ AgNO_3 \rightarrow Cu(NO_3)_2 + 2\ Ag$

Double replacement is when 2 compounds react to produce 2 new compounds. The cation of one compound replaces the cation in another compound.

General formula xA + yB → yA + xB

Example

$Ca(OH)_2 + H_2SO_4 \rightarrow 2\ HOH + CaSO_4$ (Ca^{2+} replaces $2H^+$) note: HOH = H_2O

Combustion is usually the burning of hydrocarbons in the presence of oxygen. One product is carbon dioxide when there is an excess amount of oxygen and the other is water.

Example

$CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$

This constitutes the basic principles of middle school and high school chemistry that need to be understood for students to coherently understand the principles of green chemistry and, thus, make a conviction to them to practice the principles they learn. Without this prior knowledge being obtained, students will not be able to fully understand the severity of the environmental effects current chemical practices have on the environment. If in need of any further understanding of these basic principles listed here, please look at appendix A for teacher resources.

Strategies

> "There is sufficiency in the world for man's need but not for man's greed"
>
> Mahatma Ghandi (1869 - 1948)

Now that one has a basic understanding of the problems in chemistry, what green chemistry is, and what knowledge students should have about chemistry and its practices, it is time to embark on a set of strategies to enable student understanding of both the historical perspective of chemistry as well as the current influx of the practice of green chemistry and the principles of green chemistry. The following is a set of strategies that can be used during a 4-6 week period dependant upon teaching style. It is designed for flexibility to encompass all aspects of green chemistry for a basic understanding through the application of knowledge of chemistry itself. The following strategies are laid out in a logical sequence to allow a thorough understanding of the principles of green chemistry. Following these strategies will be a section for student activities that should be utilized for the completion of this unit.

The following are the key ingredients to the unit to be discussed

1. History of chemistry and waste production
2. What is Green Chemistry
3. Stoichiometry and the atom economy
4. What can be done to change mind set and be part of a movement towards green chemistry

History of chemistry and waste production

The historical aspect of chemistry through the ages will help build the knowledge of a wasteful chemical industry even if it not readily perceived from the onset of the unit. This section can be used to have students begin work on an independent group project, this being one that requires little time used in the classroom other than allowing groups to meet for a few minutes at a time to recognize their individual progress. Meanwhile, classroom instruction time during the project phase can be used to teach the prerequisite knowledge through independent autonomous standards employed by each individual teacher. In order to perform this task, student groups for studying each area of history should be created. Students will design a 20 minute lesson for their individual time period, posters, and visual displays (PowerPoint, graphs, photos, video excerpts etc…), and a worksheet designed to focus on the main points of their time period. Students will then spend time instructing the class about these different time periods through proper chronology so as to emphasize the changes in chemistry throughout history. Students will emphasize the waste being produced during each time period. Through this emphasis on the waste being produced throughout the different time periods, students will be building a sense of knowledge of product vs. waste which will be helpful in understanding atom economy and the need for decreased waste by the chemical industry as they attempt to make and maintain a more sustainable system.

Once students have established a proper understanding of the changes through chemistry and its history, they will be introduced to stoichiometry and its function in balancing chemical equations. Students will conduct chemistry labs to determine what amount of substance is being put into the process and what amount they receive of the desired substance. Through this, they can determine a relationship to the Law of Conservation of Mass as they have an identical, or close to identical, mass after the reaction with their new products in which they had of reactants being added into the system. By developing more guidelines to certain labs stating they are only concerned with generating a specific substance, they will begin to see a relationship between desired product produced and the waste production that was also generated from the same process. The use of molecular models will further demonstrate through a hands-on approach the recombination of chemicals into a new substance as they become aware of how many molecules are being used, as opposed to those no longer needed. Using the principle of a mol, students will then be able to see the amount of atoms being discarded, and the actual mass ratio of the waste to the desired product. The use of original synthesis formulas such as ibuprofen and propene is a crucial stage for students to see how things are being made. This should be done through an in class analysis of looking at the varying stages of the production of these substances as a teacher-led activity. Students should not be aware of the newer processes being done to make the same substances; rather they should only determine that these processes generate a desired product with a certain amount of waste. As students learn about green chemistry and atom economy, they will understand how inefficient these processes are. Once students have had ample opportunity to perform these tasks they are ready to understand what green chemistry is, and the impact of green chemistry on the chemical industry.

What is Green Chemistry

Although all of the 12 principals of green chemistry should be taught in the class for a basic understanding the following, four main ideas will be emphasized the most through instruction of this unit. They are:

1. Prevent waste: Design chemical syntheses to prevent waste, leaving no waste to treat or clean up.
2. Design safer chemicals and products: Design chemical products to be fully effective, yet have little or no toxicity.
3. Design chemicals and products to degrade after use: Design chemical products to break down to innocuous substances after use so that they do not accumulate in the environment.
4. 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. [17]

Stoichiometry and Atom Economy

Students should be taught the principles behind stoichiometry and balancing equations. Students should be able to determine the molar mass of the atoms and also be able to further convert them to total atoms using Avogadro's number. Once this is understood, students can be taught about atom economy. Atom economy is an important principle of green chemistry and one that is easy for students in the middle grades to comprehend. Students should look at the photosynthesis equation which they should already be familiar with. Using this equation, they can be presented with the formula for the efficiency of the equation using the following:

[Amount of desired product (each individual atomic mass added) * 100] /

[Amount of reactants used in the equation (each individual atomic mass added)]

This gives the percent efficiency of the process. Knowing that we need all the products of photosynthesis (in so much that oxygen is reused by the animal kingdom), they should find that:

$C_6H_{12}O_6 + 6 O_2$ = [(6x12)+(1x12)+(6 x 16)] + [6(2x16)] = 372 x 100 or 100%

$6 CO_2 + 6 H_2O$

[6(1x12) + 6(2x16)] + [6(2x1) + 6(1x16)] = 372

If, however, we are only trying to determine the efficiency of glucose production as that is what is beneficial to the plants and the oxygen is actually waste, then we get

[(6x12)+(1x12)+(6 x 16)] / [6(1x12) + 6(2x16)] + [6(2x1) + 6(1x16)]

= 180 / 372 = 0.484 x100

= 48.4% efficiency

So the students would know that the waste was 51.6% of the process and not needed. Or for every 180 g of product there is 192 g of waste. Students should be able to recognize that a lot of waste formation can be found in this second set of equations as there is only one desired product from the process. Thus, there should be a different process that can capitalize on the production of the product (in this case oxygen) while accumulating less waste. Students should be presented with the task of coming up with ideas on how to get the oxygen more efficiently. After a discussion with leading questions towards finding new products that can be used to start the process that have less waste after the reaction, students can be presented with some real world examples of green chemistry in action.

Students should understand that the atom economy means that if there is less waste generated then there is more potential for greater profits by the chemical industry while also helping the environment by not adding more waste to it. When students understand this, it is time for them to revisit the production of propene and ibuprofen. Students should now conduct a discussion about how inefficient the processes are. Then they can be introduced to the current production means of both of these substances. This will give students a clear understanding of a chemical process that was done one way for many years without change, thus generating much waste, compared to the new approach being used today that produces less waste and is, therefore, more efficient by terms of atom economy. These two examples will generate the basic understanding of the principles of green chemistry. Dependant upon class structure and size there are many more examples that can be filtered in as extension and enrichment activities. See Appendix A for more resources.

Once students have become "experts" on green chemistry at their age-appropriate level, they will look at different objects they come into contact with on a daily basis and become student advocates for that particular object. Students will look at perhaps their shoes and determine what chemical process is needed to create that shoe. They will look more at a raw materials standpoint as to what is being used by certain companies to produce that shoe rather than the actual chemical make-up of all of the different parts, as that would be too high detail of an exploration for this age level. From there, they will research the possibilities of alternative materials for the shoe that will still give the same integrity to the shoe, or find other feedstocks that will have the right chemical combinations for the shoe to still be created the same way, but with less waste or less toxic release to the environment. From this knowledge, students will contact these companies' production departments, and specifically address to the VP of production for the facility. In their contact, they will lay out the concerns they have based on the waste products being generated currently and offer alternatives by providing knowledge of the 12 principles of green chemistry to the company. From this, the hope is to gain positive feedback from companies already exploring alternatives in production or will be doing so in the near future. The students may also send information to their state senator and suggest changes in importation of objects (such as tariffs) that do not follow protocols of green chemistry as a way of promoting growth of this science. This project will give students a sense of fulfillment in their understanding of this subject matter in that they will know that there are alternatives to creating the same or similar products. They will become more informed consumers in society and can help to fulfill the revolution of green chemistry in science. For a more detailed shoe example, explore Nike company's history and their new "considered" line of shoes that use water-based solvents, hemp for laces and tongues, and environmentally friendly inks and dyes. When students discover companies that have already made a transition, their project should focus on this positive characteristic. It can also be pointed out that the transportation of shoes from SE Asia still provide a negative impact on the environment, so although the manufacturing has gone green there is more that can be done.

Conclusion

The ultimate goal is not to create a new generation of scientists eager to change the world. Instead the goal is to create a group of students that become more knowledgeable about the chemical process of the past and the potential ways that can change in the present and in the future. By understanding the environmental impact of chemical waste and working through the student advocate project, these students will hopefully become lifelong supporters of the environmental movement as a whole, and specifically be more concerned with the products they personally purchase knowing they would be better if they were being produced using the principles of green chemistry to help lower the overall waste products. Through continued deployment of this unit, whole groups of students will change their practice of what they purchase and use, and have a reason for voicing concerns over how products are being produced.

Student Activities

Please refer to teacher appendix for additional resources for use in teaching this unit and enrichment activities.

History Project

The history project is designed for the students to have to research in groups independent of classroom time. The groups can be chosen by any means and can have from 3 - 5 students dependant upon class size. The groups should be separated by the following categories:

Ancient Chemistry: These students will research chemistry of antiquity, the first metallurgy, dyes for pottery, weapons, textiles, through the age of the Roman empire.

Alchemy: This group will study the rise and spread of alchemy and its relationship to modern day chemistry. The time period goes from 500 AD through 1500 AD

The age of reason: This group will study changes in chemistry from the renaissance through to 1750.

The beginning of today: this group will focus on discoveries and practices form 1750 through the beginnings of the industrial revolution stopping at 1810

Early modern Chemistry: This group will study the achievements of the nineteenth century chemists including the creation of the periodic table

Petrochemical industry: this group will study the rise of chemical industry through the use of petroleum products

World War I & II : this group will focus on the chemicals created during war time for both pesticide use as well as chemical warfare.

Rachel Carson: This group will study the rise of the environmental movement, the writing and effect of Silent Spring and what Rachel Carson did.

Chemistry from 1965 through today: This group will study the chemical industry from the beginning of the environmental movement through to today.

Student Focus:

All groups must research the following for their time period:

1. type of chemical processes used, and types of products being created
2. new knowledge over previous time period and change to industry
3. types and amount of waste generated from synthesis process
4. notable people of the time period that were part of chemistry and their contributions to the science
5. consumer needs for chemical industry

Students must create a 20 - 30 minute lesson for their time period. This lesson must include all parts of their research presented using some sort of visual display (posters power point, transparencies, internet simulations, brief documentary pieces). All group members must be part of the presentation of the project, each taking a different subsection of the research (thus individual grading can still occur). The end of the presentation should include a short form for analysis of information obtained. This can be a worksheet, quiz, game or other form, but should take no more than 10 minutes to complete.

*** When students are completing this research using time during instruction is a perfect opportunity to teach the various items found in the prerequisite knowledge section.

Grading of a project of this magnitude should be worth multiple grades in these subsets:

Presentation

Individual Grade

Knowledge obtained / Research

Assessment

A Rubric can be made for equity in grading using the rubric maker found at

http://www.teach-nology.com/web_tools/rubrics/sciences/

Stoichiometry

Balancing Equations Practice Worksheet

Balance the following equations:

1) ___ $NaNO_3$ + ___ PbO → ___ $Pb(NO_3)_2$ + ___ Na_2O
2) ___ AgI + ___ $Fe_2(CO_3)_3$ → ___ FeI_3 + ___ Ag_2CO_3
3) ___ $C_2H_4O_2$ + ___ O_2 → ___ CO_2 + ___ H_2O
4) ___ $ZnSO_4$ + ___ Li_2CO_3 → ___ $ZnCO_3$ + ___ Li_2SO_4
5) ___ V_2O_5 + ___ CaS → ___ CaO + ___ V_2S_5
6) ___ $Mn(NO_2)_2$ + ___ $BeCl_2$ → ___ $Be(NO_2)_2$ + ___ $MnCl_2$
7) ___ $AgBr$ + ___ $GaPO_4$ → ___ Ag_3PO_4 + ___ $GaBr_3$
8) ___ H_2SO_4 + ___ $B(OH)_3$ → __ $B_2(SO_4)_3$ + ___ H_2O
9) ___ S_8 + ___ O_2 → ___ SO_2
10) ___ Fe + ___ $AgNO_3$ → ___ $Fe(NO_3)_2$ + ___ Ag

Demonstrating the Stoichiometry of a Chemical Reaction with Baking Soda and Vinegar

Many students have been introduced to the chemical reaction of baking soda and vinegar throughout their school years. This lab is another way of interpreting the same reaction to visually understand chemical properties and synthesis more clearly. A common way to do this is to stretch a balloon, pre-filled with a certain amount of baking soda, over a flask in which some vinegar has been added. Tipping up the balloon causes the baking soda to mix with the vinegar and the resulting reaction produces gas that pumps up the balloon. Balloons expand to different extents depending on how much carbon dioxide gas is produced and this depends on the quantity of baking soda and vinegar used.

Equipment

Scale (to 0.1 grams)

Erlenmeyer flask (100 ml minimum)

Small Balloons

Baking Soda

Vinegar

Procedure

Read entire document, then ask questions before proceeding with lab

Create a data table for the mass of each object before and after reaction

Mass the empty balloon and the empty flask

Measure out 4 g sodium bicarbonate and place inside balloon.

Add 2 tablespoons of vinegar (30 ml of 5% acetic acid) into a 100 ml flask

Mass the vinegar and flask combination to determine the mass of vinegar

Stretch the mouth of the balloon over the mouth of the bottle then turn the balloon completely upright so that the baking soda inside the balloon pours into the vinegar.

When reaction is complete carefully remove balloon and tie off without letting gas escape.

Take balloon and place on scale to determine mass of gas inside balloon.

Assuming the gas was the only thing desired as a result of the reaction answer the questions in the analysis.

Assuming the following is the reaction for this lab, answer the following:

$CH_3COOH + NaHCO_3 \rightarrow CH_3COONa + H_2CO_3$

$H_2CO_3 \rightarrow H_2O + CO_2$

Analysis

1. Place balloon with gas on scale to obtain mass of gas and place in data table.
2. Mass contents of flask by placing on scale
3. Add mass of gas and contents of flask to determine full mass of all products.
4. Describe the entire reaction from beginning to end in one short paragraph. Be sure to include temperature change, reaction sequence, what it looks like before and after reaction, etc…
5. Determine if the conservation of mass was achieved by adding mass of all reactants and comparing to mass of all products.
6. Determine the appropriate labels (what is each substance) for the above equations and apply labels by rewriting on your own paper.

7. Determine atom economy for the equation based on the assumption that the trapped gas was the only product that was desired. Use your notes to determine atom economy and show all work for this in molar mass.
8. Based on the efficiency of this synthetic process, extrapolate out the need for 1000 kg of CO_2 gas using the same synthetic method. What would the amount of waste product be? Is this an efficient process?
9. What in your opinion could be done to improve the efficiency of this reaction to reduce the overall waste? List several.
10. What was left over after the reaction? Was all the vinegar used? How about all the baking soda?
11. What is the new substance in the flask? If the process was not complete, or even if it was, explain why in terms of solubility.

Polymer Ball Lab

Due to limited space available please proceed to the following site for this lab:

teachers.sduhsd.k12.ca.us/ccollins/Polymers lab.doc (public domain site courtesy)

Student advocacy Project

This project is designed to involve you the learner as a valid advocate for support of green chemistry in society. You now have a brief understanding of the principles of green chemistry most notably #'s 1, 2, 10, & 12 from the list of principles of green chemistry (if unsure, look back at your notes now). Using this knowledge of green chemistry, you will embark on a research project that will ultimately put you in contact with one of the following:

A company that does not use the principles of Green Chemistry and is unsure about how to implement them.

A company that has already begun using the principles of green chemistry in their products.

A politician at the state or federal level that has interest in green chemistry and its potential as use in creating new environmental legislation.

You may not know who you will be in contact with as you start this project as the project itself will become a learning exercise and will develop along with your level of education. Remember to use your zealousness as a pro green chemistry advocate every step of the way through this project understanding that no company will be perfect and very few if any chemical processes will be purely green. Instead you will be looking for the adaptation, and to what level the adaptation is being made to adhere, to the principles of green chemistry.

The Project:

A group of three (four when needed based on class size, two when no other choice is available, never solo, and never more than four) students chosen either randomly or by students dependant upon nature of students will form the brain trust of the project.

Each group will look around at their lives and lifestyle and choose one product that is an important part of their daily lives and routines (With the exception of shoes as this has already been discussed in class). Once this project is chosen, whether it be mp3 players, game systems, clothing, jewelry, or some other object students must approach the teacher and get approval of this product before proceeding further.

Research Phase:

Once approval of the project has been established, each person in the group should independently pursue research on the production of the same general product from a variety of manufacturers (i.e. for sneakers you could research Nike, Adidas, Reebok, New Balance, etc…). You want to create a data table of the different raw materials, or chemicals used in the manufacture of the product. This research should also include how these materials are acquired (mined, manufactured at other sites, etc…) and used in the manufacture of the final product for consumer use. Do not forget the packaging that the product comes in, as this is still a part of the manufacturing process. It is better to have more research at this point than too little. Get together and compare data with others in the group periodically to get a thorough education of the manufacturing process of this product, understanding what general wastes are associated with the manufacture of this product. Create a plan for how to address the issues that have been found regarding the manufacture of your chosen product. Conference with the teacher for guidance about findings and what direction the group should focus on from this point forward. This is an important step in this project to ensure a well thought out design.

Address the issues:

Based on the research, subdivide the group into one person to find a political ally in green chemistry. This person should interview a politician or politician's office as to their stance on certain manufacturing processes after you share your valuable education with them about green chemistry. The interview should include questions about policy and potential new legislation that relates to green chemistry and the principles of green chemistry. This interview should be a minimum of ten questions and must be approved by the teacher before the interview can take place. The answers should then be transcribed onto paper, or e-mail the questionnaire to their office after verbal dialogue to have a hard copy of their record.

The other two individuals will pick a company, a person to contact and determine if they are utilizing any practices of green chemistry. This can be done through the education resources of the company, or the companies' public administrator that addresses questions from the public on their manufacturing process. Understand that some questions about green chemistry may be new to them as it is a new science. Act professionally and ask them to get back to you with further clarification of any items they have trouble initially answering. Similar to the person above, this should be achieved by developing a set of interview questions based on the research done on the manufacturing of these products. The questions should be specific rather than general so that the answers can also be specific. Again the questions need to be approved by the teacher before the interview session. The interview again must be transcribed in writing to a hard copy that will eventually be turned in with the final project. With all luck, one person will find a company doing a lot in green chemistry, while the other will not, showing a range in manufacturing. If you find that neither company is doing anything you may want to continue searching for a few more companies to find one that does employ some form of green chemistry in the manufacturing process.

Develop a plan:

The group will have to report their findings back to the class with each person having a five minute report based on their findings. This presentation must have some form of visual aid which could be a display board, computer program such as power point, or an infomercial self-created about the chosen product and its manufacturing process. Data are important to include in this report so charts and diagrams showing waste and efficiency would enhance the overall project. Graded as a group and individually.

Finally the group will have to prepare a written research report describing their entire project from beginning to end. This should be no more than 15 pages total for the entire group and includes the transcribed interviews conducted during the research. This does not include bibliography, acknowledgements, or title and contents page. Graded as group for multiple grades should be written independently for different parts and then combined into one paper.

Appendix A

Teacher Resources

Standards that are met by the completion of this unit satisfy the objectives and standards of the State of Georgia as follows:

S8P1 Students will examine the scientific view of the nature of matter.

S8P1

a. Distinguish between atoms and molecules.
b. Describe the difference between pure substances (elements and compounds) and mixtures.
f. Recognize that there are more than 100 elements and some have similar properties as shown on
g. Identify and demonstrate the Law of Conservation of Matter.

Twelve Principles of Green Chemistry

1. It is better to prevent waste that to treat or clean up waste after it is formed.
2. Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.
3. Wherever practicable, synthetic methodologies should be designed to use and generate substances that possess little or no toxicity to human health and the environment.
4. Chemical products should be designed to preserve efficacy of function while reducing toxicity.
5. The use of auxiliary substances (e.g. solvents, separation agents, etc.) Should be made unnecessary wherever possible and, innocuous when used.
6. Energy requirements should be recognized for their environmental and economic impacts and should be minimized. Synthetic methods should be conducted at ambient temperature and pressure.
7. A raw material of feedstock should be renewable rather than depleting wherever technically and economically practicable.
8. Reduce derivatives - Unnecessary derivatization (blocking group, protection/deprotection, temporary modification) should be avoided whenever possible.
9. Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.
10. Chemical products should be designed so that at the end of their function they do not persist in the environment and break down into innocuous degradation products.
11. Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.

12. Substances and the form of a substance used in a chemical process should be chosen to minimize potential for chemical accidents, including releases, explosions, and fires. [18]

From this list of principles emerge five main foci:

1. less,
2. safe,
3. process-oriented,
4. waste-reducing,
5. sustainable.

These key words can then be grouped around this simpler form of:

1. uses fewer chemicals, solvents, and energy
2. has safe raw material, processes, and solvents
3. process should be efficient, without waste, without derivatization, and should use catalysts
4. waste generated should be monitored in real time and should degrade
5. all chemicals, raw materials, solvents, and energy should be renewable or sustainable.

History Project: MSN Encarta. Britannica online, ACS (American Chemical Society) website This is only a short list as there are plenty of sources for students to use to compile their research for the history project.

Students should be taught about balancing equations and the conservation of mass. Use explorelearning.com to have students try balancing several equations (if your school does not have a license for this you can obtain a 30 day trial period to complete the chemistry activities). There are other resources for chemistry also available at that site.

The following site is for propene manufacturing and ibuprofen with lab and questions.

http://www.greeningschools.org/docs/WasteandTinkerToysAtomEconomy.pdf

The following is a list of sites that can be adapted for instructional use in completing the various parts of the lesson. Some are better for lecture as some are more directed for student exploration:

http://www-users.york.ac.uk/~chem56/index.htm

http://www.greenchemex.org/about?content_id=110

http://portal.acs.org/portal/acs/corg/content?_nfpb=true&_pageLabel=PP_SUPERARTICLE&node_id=1444&use_sec=false&sec_url_var=region1

http://www.rsc.org/chemsoc/gcn/index.htm

http://www.carolina.com/category/teacher+resources/green+chemistry/introduction+to+green+chemistry.do

http://www.chem.ufl.edu/~itl/2045/lectures/lec_3.html

http://academic.uofs.edu/faculty/cannm1/organicmodule.html

http://www.creative-chemistry.org.uk/

http://chemistry.about.com/cs/howtos/a/aa052703a.htm

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Endnotes

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[2] Kuhn, Thomas S.. The Structure of Scientific Revolutions. 97.

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[4] Anastas, Paul T., and John C. Warner. Green Chemistry: Theory and Practice. 2.

[5] "History of Chemistry - MSN Encarta." MSN Encarta

http://encarta.msn.com/encyclopedia_761569628/History_of_Chemistry.html (accessed July 12, 2009).

[6] Anastas, Paul T., and John C. Warner. Green Chemistry: Theory and Practice. 8.

[7] "Green Chemistry Resources." University of Oregon. http://www.uoregon.edu/~hutchlab/greenchem/resources.html (accessed July 12, 2009).

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[9] Manahan, Stanley E.. Green Chemistry and the Ten Commandments of Sustainability, 2nd ed. 160-194.

[10] Manahan, Stanley E.. Green Chemistry and the Ten Commandments of Sustainability, 2nd ed. 160-194.

[11] Doble, Mukesh, and Anil Kumar. Green Chemistry and Engineering. 10-11.

[12] Doble, Mukesh, and Anil Kumar. Green Chemistry and Engineering. 171-180.

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