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The Chemistry of Energy

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Introduction

In April 2020, the oil barrel price was $14.28 in Oklahoma[1] creating an unprecedented economic crisis not only in the state but also in the world. The gasoline price at the gas station in Tulsa dropped below two dollars a gallon. During several months the oil companies were looking for places to store the oil. The capacity of the reservoir tanks was up to the limit. One of the world's storage locations with 91 million barrels of capacity is located in Cushing, Oklahoma, 50 miles Southwest of Tulsa. This place was already full of oil because of the lack of demand, and the stay at home implementation due to Corona Virus Pandemic (COVID-19).

The oil crisis revealed how vulnerable it is for the state and the city to extract oil to be used as one of the primary sources of energy. Many countries are looking for diversifying the way they produce energy in order to be more sustainable. At the same time, to impact less the environment, looking at other sources of energy different from fossil fuel.

Energy has been repeatedly addressed from different angles by different sciences such as Physics, Chemistry, Environment, and Economic. Energy has been studied systematically; because of the importance of its use and consumption of energy. Energy is something vital for the development of any country. There is no sphere of daily life where it is not reflected in the use of electricity. That is not to mention the big factories that are the largest consumers of energy and that we could not enjoy the material goods we currently have.

The production and consumption of fossil energy have negative impacts on the environment; for instance, due to the combustion of fossil fuel, there is an increment of carbon dioxide in the atmosphere, provoking the greenhouse effect (which is increasing the temperature of the Earth). Current concerns regarding the long-term availability of fossil fuels and global warming due to carbon dioxide (CO_2) emissions have led to a search for an alternative fuel that does not have these problems.[2] Other gases released in the combustion of hydrocarbons like NO_2 and SO_2 also contribute to the formation of acid rains that can decrease the pH of rainwater affecting crops, buildings, monuments, and any other solid structure with calcium carbonate in their composition.

The Energy Chemistry Unit is part of the Thermochemistry chapter included in the Chemistry curriculum. Students will study concepts and laws like Hess's Law, exothermic and endothermic process, enthalpy, energy conservation, and different types of energy.

This Unit is mainly for students at High School, particularly those taking advanced Chemistry classes such as AP (Advanced Placement), IBSL (International Bachelorate Standard Level), and IBHL (International Bachelorate Advance Level). This Unit's main objective is to study the different ways of producing energy where chemical reactions are present, such as the combustion of fossil fuels, nuclear reactions, hydrogen, and oxygen reaction and the use of solar energy to produce electrical energy. While the study of this Unit will address not only the production of energy but also the advantages and disadvantages that bring production and consumption, the twelve principles of Green Chemistry will be used.

Content Objectives

To apply the concepts and laws of energy under the chapter of Thermochemistry such as Energy Conservation, Efficiency, Enthalpy, Exothermic, and Endothermic through examples of energy.

To compare the different sources of energy, considering the advantages and disadvantages of production and consumption.

To analyze the environmental impact of the sources of producing energy using the twelve principles of Green Chemistry.

Rationale

Booker T. Washington (BTW) is a world-class high school in Oklahoma under the administration of Tulsa Public School District. In 2009 and 2016, the school received the coveted distinction of being a Blue Ribbon School recognized by the United States government for being academically superior. The school is ranked as one of the top high schools in America. It was founded in 1913 to serve the citizens of the African-American community; Booker T. Washington was chosen in 1973 to be the vehicle for Tulsa's school desegregation program.[3] The school composition is mainly African Americans with a significant representation of the White and Hispanic populations. In the last few years, there was an increment in the Hispanic population in the school. BTW high school is a high performing public magnet school that offers students the option of earning the International Baccalaureate Diploma upon completing a rigorous academic curriculum.

I teach Chemistry at Booker T. Washington high school in Tulsa, Oklahoma. There are four Chemistry course delivery levels: General Chemistry for 10-grade students, Advance Chemistry for 10-grade students who are planning to enroll AP (Advanced Placement) Chemistry when they are in 11 grade. AP Chemistry for 11-grade students and IBSL (International Baccalaureate Standard Level) and IBHL (International Baccalaureate Higher Level) for students in 11 and 12 grades, respectively. The main difference between those courses is that the level of depth those courses are covering different topics.

Although this Unit can be taught to students in grades 10, 11, and 12 who are taking Chemistry classes, the group of students who will benefit from this Unit is the International Baccalaureate (IB) students High Level (IBHL) and Lower Level (IBSL).

The High-Level International Bachelorate are enrolled first in the IBSL's course; then, the students need to spend 2 years taking Chemistry class. The IBHL students will need to take an exam, participate in a research project, and write an essay. After the IBHL is completed, the students can receive credit hours when they are enrolled in some universities or colleges that recognized the IB program. The IBSL students only take one year of Chemistry classes and take an international test and write an essay about any topic they chose.

Under the Thermochemistry Chapter, some concepts, such as enthalpy, heat, endothermic, exothermic, Hess law, specific heat are addressed. However, very rarely are real examples of ways to produce energy using chemical reactions available to them, so in this Unit, we will focus mainly on energy production where chemical reactions are the primary sources of generation, among which we can cite those below. The sources of energy that the students will cover are Fossil Fuels, Nuclear Energy, Solar Energy, and the reaction of hydrogen with oxygen to produce water.

The previous four topics that the IBHL' students need to choose as part of the IBHL final test, and they have to answer a free response based on any of these items: Energy Sources, Fossil Fuels, Nuclear fusion and fission, Solar Energy and the impact of those sources of energy in the environment, making emphasis in the global warming.

The IBSL students will have the opportunity of applying this Unit under the Thermochemistry chapter. They are required to write an extended essay on the topic they choose. Energy will be a suitable topic for them to write an essay, particularly at this point on time, where there are many concerns about the environmental impact of burning fossil fuels.

Content Background

Electricity has revolutionized the quality of human life since the end of the nineteenth century, allowing more accessible energy sources. New devices and applications such as dynamo and electric lighting motivated direct current. Later the alternator and alternating permitted current electrical energy to be transformed and transmitted on a large scale.

Currently, the oscillation of energy demand is covered by the on/off generators. However, electricity is difficult to store for later use. The best system in terms of efficiency and cost is also more widespread for the storage of energy from a large-scale grid is pump storage, which consists of pumping water to a higher dam and generating the electricity demanded by hydroelectricity. However, this method does not work for mobile energy storage applications. There are smaller storage alternatives such as capacitors, but they have the problem of low energy density. Batteries also have low energy density and take time to charge and discharge.

Around the same time that electricity began to run, a portable power source was discovered. These are naturally internal combustion engines, which burn hydrocarbons. Internal combustion engines devastated their competitors, such as compressed air or steam engines. They provided greater possibilities under the efficiency of the internal combustion engine and the high energy density of fuel, even though they contributed to climate change and exploited people in emerging countries.

What is energy?

Energy, in physics, is the capacity for doing work. It may exist in potential, kinetic, thermal, electrical, chemical, nuclear, or other various forms. Moreover, there are heat and work—i.e., energy in the transfer from one body to another. After it has been transferred, energy is always designated according to its nature. Hence, heat transferred may become thermal energy, while work is done may manifest itself in the form of mechanical energy.[4]

What are the renewable resources that produce energy?

Renewable energy, also called alternative energy, usable energy derived from replenishable sources such as the Sun (solar energy), wind (wind power), rivers (hydroelectric power), hot springs (geothermal energy), tides (tidal power), and biomass (biofuels).[5]

Non-renewable energy

A non-renewable resource (also called a finite resource) is a natural resource that cannot be readily replaced by natural means at a quick enough pace to keep up with consumption. An example is a carbon-based fossil fuel. With the aid of heat and pressure, the original organic matter becomes a fuel such as oil or natural gas. Earth minerals and metal ores, fossil fuels (coal, petroleum, natural gas), and groundwater in certain aquifers are all considered non-renewable resources. However, individual elements are always conserved (except in nuclear reactions).[6] Non-renewable resources can eventually become unavailable because there is no way to replenish the ones already used; for instance, by burning oil, the composition of matter produces a chemical reaction producing water, carbon dioxide, and many other sup products. It is not easy to make this reaction reversible even thermodynamically, but the economic point of view will be too expensive.

Fossil fuels

Fossil fuel[7] that comes from the biomass produced in past eras, which has suffered burial and behind it, transformation processes, by increasing pressure and temperature, until the formation of substances of high energy content, such as coal, oil, or natural gas. Since it is not renewable energy, it is not considered as biomass energy.

Most of the energy currently used in the world comes from fossil fuels. They are used for engine fuel, electricity generation, air conditioning environments, and cooking. Most countries in the world are trying hard to reduce or eliminate fossil fuels' use due to climate change. They may be the most common now, but chemists and engineers who want to have a future in energy, are working on renewable fuels.

Examples of fossil fuels[8]

Coal is a dark black sedimentary rock, rich in carbon and other chemical elements such as hydrogen, sulfur, oxygen, and nitrogen. The extraction of this mineral can be done in two ways: through open-pit mining (when coal is less than 60 meters deep) or through underground mining. Between the nineteenth and mid-20th century, trains, ships, and industrial machinery operated thanks to this fuel's energy. Despite being overtaken by oil in terms of its energy capacity, coal is used to produce plastics and lubricants, among other uses.

Oil is a liquid more or less viscous composed of carbon and hydrogen (conjunction called "hydrocarbon") extracted from a well, between 600 and 5000 meters deep. Drilling towers are installed that can be located on the Earth's surface or platforms at sea. From petroleum can be produced plastic, printing inks, rubber for the manufacture of tires, gasoline, among the main ones of a long list.

Natural gas is a mixture of hydrocarbons in the gaseous state, mostly methane and smaller quantities, nitrogen, carbon dioxide, butane, among others. Most natural gas can be found a few thousands of meters under the Earth's surface, but some locations can be at least 4500 m deep. It is extracted from subsurface formations with drill towers and, by pipes designed to transport gases on a large scale, is directed to the plants for further transport by sea. Drilling for deep natural gas is not always economically feasible. Methane has no odor and is colorless; that is, we cannot perceive it with the senses. Therefore, an odor product is added to detect it in cases of leakage.

Liquefied petroleum gas is composed mainly of butane and propane gases that are compressed into liquids. It is obtained as a by-product of the oil or natural gas refining process and primarily used as an alternative fuel for gasoline-powered cars. These are adapted to work with both gasoline and liquefied petroleum gas. Despite generating a lower power than gasoline, its differential advantages are the economical price and the lower emission of carbon dioxide, as seen in Table 1.

Table 1. Energy Content of Fossil Fuels.[9]

Source of Energy	Hydrogen/Carbon ratio	Energy Content kJ/g	CO_2 releases (mole/10^3 kJ)
Hydrogen	N/A	120	Doesn’t release CO_2
Gas	2/1	51.6	1.2
Petroleum	1/1	43.6	1.6
Coal	1/1	39.3	2.0
Ethanol	3/1	27.3	1.6

Chemical reactions related to the burning of fossil fuels and the products considered as pollutants produced are carbon monoxide (CO), carbon dioxide (CO_2), sulfur dioxide (SO_2), a mixture of nitrogen oxide (like NO_2, N_2O), Volatile Organic Compounds (VOCs), hydrocarbons and many other solid products. Some of these gases released by the combustion of fossil fuel like SO_2 and NO_x, react with water falling to the ground as acid rain (mainly H_2SO_4 and HNO_3.[10]

The hydrocarbons have combustion reactions, in which they combine with oxygen to give rise to carbon dioxide and water:

Hydrocarbons + $O_2 \rightarrow CO_2 + H_2O$

The fundamental feature of combustion reactions is that they release much energy in the form of heat; that is, they are highly exothermic, so historically they have been used as fuel. Examples include methane, propane, or butane.

Nuclear power

Nuclear or atomic energy[11] is the one that is released spontaneously or artificially in nuclear reactions. Controlled nuclear reactions can be used for obtaining electrical energy, thermal energy, and mechanical energy. Thus, it is common to refer to nuclear energy not only as of the result of a reaction but as a broader concept that includes the knowledge and techniques that allow the use of this energy by the human being.

These reactions occur in the atomic nuclei of some isotopes of certain chemical elements (radioisotopes), the most well-known being the fission of uranium-235 (235U), with which nuclear reactors operate, and the most common in nature, inside the stars, the fusion of deuterium-tritium (2H-3H). However, to produce this type of energy, nuclear reactions can be based on other isotopes, such as thorium-232, plutonium-239, strontium-90, or polonium-210 (232Th, 239Pu, 90Sr, 210Po; respectively).

Solar energy

Solar energy[12] is renewable energy, obtained from the use of electromagnetic radiation from the Sun. Since ancient times, the solar radiation that reaches Earth has been harnessed by humans by different technologies that have evolved. Today, heat and sunlight can be harnessed through various collectors such as photoelectric cells, heliostats, or solar collectors, and can be transformed into electrical or thermal energy. It is one of the so-called renewable energy or clean energy, which could help solve some of the most urgent current problems facing living beings.

Different solar technologies can be classified as passive or active as they capture, convert, and distribute solar energy. Active technologies include the use of photovoltaic panels and solar thermal collectors to collect energy. Passive techniques include different techniques framed in bioclimatic architecture: the orientation of buildings to the Sun, the selection of materials with a favorable thermal mass, or that have properties for the scattering of light, and the design of spaces by natural ventilation.

Hydrogen

Hydrogen[13] is the most abundant element in the universe because 90% of matter is made up of hydrogen. It is often combined with other elements in its composition, such as water (H_2O) and other organic elements. It is odorless, colorless, and tasteless in its non-gaseous natural form. It is non-toxic and can be breathed safely. It is extremely light and rises rapidly from the Earth's surface to the atmosphere. From this, we can point out the possibility of using hydrogen as energy, although it is not a force that produces energy on its own. Hydrogen is a vector as it does not exist isolated in nature and cannot be extracted from anywhere at a low cost. This means that if we want to use hydrogen for any purpose, we must generate it first, a process in which more energy is always consumed than you get later when using it. The combustion reaction of hydrogen can be represented by the following balanced equation:[14]

$2H_2\ (g) + O_2\ (g) \rightarrow 2H_2O\ (l)$

This reaction is exothermic. During the combustion of hydrogen -482 KJ is being released from the reaction; this energy can be used for producing electricity; the most important thing is that there is no carbon dioxide being released, which is one the gases causing the greenhouse effect.

Hydrogen energy is an alternative energy source that can be used instead of coal or oil. How to transform this energy element? Hydrogen can be transformed thanks to technology like that used for the manufacture of batteries. This releases electricity, heat, and water (H_2O).

In the Table 2, a summary of some advantages and disadvantages of using some of the sources energy.

Table 2. Advantages and disadvantages of different sources of energy.

Sources of Energy	Some Advantages	Some Disadvantages
Fossil Fuels	They are very energetic Easily storable and transportable. Easy to extract	Are not renewable Its extraction and combustion increase the proportion of greenhouse gases, such as methane and carbon dioxide. Its combustion and processing release toxic elements, such as arsenic and mercury Geographical distribution is not homogeneous.
Nuclear	It does not emit CO_2 into the atmosphere avoiding an increase in the greenhouse effect. Less dependence on oil Energy is obtained in large quantities from a small amount of fuel.	Radioactive waste The lifespan of nuclear plants is only about 40 years. Nuclear reactor incidents It is a form of energy with high start-up costs, and the management of radioactive waste, installations, and maintenance.
Solar Energy	Renewable energy source Reducing dependence on fossil fuel energy and reducing emissions of greenhouse gases. The maintenance of solar energy collection systems is low once installed. In some places where access to the public electricity grid is restricted, the use of photovoltaic systems is an acceptable option.	Technology to collect and produce large-scale electricity from solar energy requires large tracts of land to compete with land for agriculture or forests. The initial investment of the photovoltaic system's purchase is high compared with the use of fossil fuel. Climate-dependent Disposition and recycling of toxic materials. Low energy production efficiency
Hydrogen	It is taken from the water and then oxidized and returned to the water Hydrogen could be much safer as energy than any other type of fuel. If released and dissipated, it would not contaminate people or the environment. High efficiency	Storage: At room temperature, it is excessively bulky, and to keep it at -253 ^{o} C we need a high energy consumption. It is very flammable when released. The sustainable production of hydrogen is so far economically not feasible yet.

Principles of Green Chemistry

One of the most critical aspects of the production and consumption of energy is the environmental impact. That is why we need to take into account the principles of Green Chemistry to minimize the side effects of this part of our lives.

Green Chemistry is the design of products and chemical processes that diminish the production of toxic substances like the emission of CO_2 or other gases that can negatively impact the environment.

By following those principles[15] we can produce and consume energy without impacting negatively or with minimum impact on the environment, the principles listed below apply to any form of producing energy. They are explicit instructions on how to deal with the negative impacts explained before, like the greenhouse effect, which is the process by which the planet's surface is warmed by the presence of some gases released by the combustion of hydrocarbons.

Prevention: It is better to prevent waste than treat or clean up waste after it has been created.

Atom Economy: Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.

Less Hazardous Chemical Syntheses: Wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment.

Designing Safer Chemicals: Chemical products should be designed to preserve the efficacy of function while reducing toxicity.

Safer Solvents and Auxiliaries: The use of auxiliary substances (e.g., solvents, separation agents) should be made unnecessary wherever possible and innocuous.

Design for Energy Efficiency: 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.

Use of Renewable Feedstocks: A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.

Reduce Derivatives: Unnecessary derivatization (use of blocking groups, protection/ deprotection, and temporary modification of physical/chemical processes) should be minimized or avoided if possible because such steps require additional reagents and can generate waste.

Catalysis: Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.

Design for Degradation: Chemical products should be designed to break down into innocuous degradation products at the end of their function and do not persist in the environment.

Real-time analysis for Pollution Prevention: Analytical methodologies need to be further developed to allow real-time, in-process monitoring, and control before the formation of hazardous substances.

Inherently Safer Chemistry for Accident Prevention: Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires.

Teaching Strategies and Activities

IBHL students' program will develop seminars explaining sources of energy where a chemical process is present. During the seminar, the students will be orally presenting a topic of one of the sources of energy discussed in this Unit: Fossil fuel, Nuclear Energy, Solar Energy, and Hydrogen combustion.

Each presentation will be graded based on a rubric created for this particular activity.[16] One important thing to keep in mind is that all the students will participate assessing the presentation.

Some of the items included in the rubric are:

Nonverbal skills: eye contact, body language, poiseVerbal skills: Enthusiasm, elocutionContent: subject knowledge, organization, and mechanics.

Writing Extended Essays for IBHL students of 11 and 12 degrees using some of the Unit's topics and emphasizing the environmental impact of each, using the 12 principles of Green Chemistry.

Performing laboratory experiments where they apply concepts and laws related to Thermochemistry. One of the activities will be determining the heat of solution of solid[17] using a calorimeter. Another experiment that the students can do is to calculate the enthalpy of combustion using a Calorimeter.[18] During the realization of the labs as mentioned earlier, the students will need to apply their knowledge and skills to Thermochemistry; concepts like Hess Law, Heat, Endothermic, and Exothermic will be to be used.

One of the experiments they can do is burning different materials: paper, wood, alcohol, oil. The students will get a beaker with water and assume that they will measure the heat absorbed by water to determine the material that will release the higher amount of heat, keeping in mind that they will be some heat lost by going to the surroundings.

Another interesting experiment to assign to the students will be to calculate how much a cold liquid, such as milk, must be added to another hot liquid (coffee) to reach a particular temperature, for instance, 70 ^{o} C. The students will need to use the formula $Q=m*C*\Delta T$ where m is the mass of the liquid used, Q is the heat absorbed (+) or released (-), C is the heat capacity, and ΔT the difference in temperature (Final temperature-initial temperature, $\Delta T=T_f-T_i$).

Because the hot liquid is releasing the heat to the cold liquid, the overall formula should be -Q (hot liquid) = Q (cold liquid). Combining this formula, the students will need to finally use the following formula:

- m (hot liquid) * C (hot liquid)* ΔT (hot liquid) = m (cold liquid) C (cold liquid) ΔT (cold liquid)

At the end of this experiment, the students will need to perform it a Laboratory setting where they will use thermometers, beakers, and graduated cylinders to check if they previous calculation where right.

Another activity suggested for this energy topic will be using the following resources online to assign reading, videos, or projects that students can learn more about the different sources of producing energy. Some of the resources are:

Newsela is an education website focused on building student reading comprehension by providing high-quality news articles and real-time assessments for students in grades 2–12. One example of this activity will be assigned a reading following a quiz of the following articles: What is nuclear energy, and is it a viable resource?[19] , and Types of renewable energy [20] (Nunez, 2019, 2020).

The TED-Ed project — TED's education initiative — makes short video lessons worth sharing, aimed at educators and students. One example of an activity for the student will be assigned the following video’s lesson how do solar panels work? - Richard Komp[21] . After watching the video, the students will need to answer some of the free responses or multiple-choice questions [22] listed below, and they will be graded.

What is light?

What are the significant physical barriers to using solar cells and modules?
What are the significant social and political barriers to using solar energy?
What are most solar cells made from?
What is the carrier of the electric current from solar cells?
What from the Sun causes the solar cell to produce electricity?
What creates the potential difference (voltage) in a solar cell?
How efficient are the normal commercial solar cells?

EDpuzzle is a teaching tool used to place interactive content into pre-existing videos from various sources, such as TED or YouTube, or into videos you have made. One example of the video with a quiz inserted on it will be Types of Energy and Energy Conversions[23]

For assessment the students will be using online tools for Quizzes and tests using some of the tools available on Internet like: Zipgrade[24] and Quizziz.[25] Below are some of the questions that the students will need to answer using Quizziz related to energy, this tool can be used not only to grade the students but also to practice some of the topics explained in this Unit. You can assign points for completion or just for the correct answer. Using Quizziz also let the students to play as a game, which increases the motivation and engagement of the students.

Why solar energy is considered renewable energy?
What is a renewable resource?
What is given off as waste in a hydrogen-fueled car?
If a tractor-trailer truck is 20% efficient, what happened to the other 80%?
What is the advantage of nuclear energy?
What is a half-life?

Conclusions

All the students must understand the pros and cons of the current ways to produce energy using chemical reactions like combustion, nuclear reactions, hydrogen, and reactions taking place using solar energy in order to make them more aware of the impact we are making in our environment.

Grades 10, 11, and 12 include their curriculum the study of energy under the Thermochemistry chapter, but unfortunately not always those topics are taught linked to the current environmental issues in their community or the problems we are currently facing globally.

The use of fossil fuel for producing energy is slowly declining, giving more space for renewable sources of energy like solar, nuclear, and hydrogen. A lot of emphasis are giving to use renewable energy like the one provide by the sun light, hydrogen or atomic energy.

One of the main significant concerns in using energy is to minimize the impact on the environment. That is why many scientists are currently working to recycle more and produce energy by using environmentally friendly sources. Following the twelve principles of green Chemistry is a useful guideline for make the production of energy more environmental friendly.

Appendix:

Oklahoma Academic Standards for Science Chemistry

CH. PS1.4 Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.

CH. PS1.8 Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay.

CH. PS3.3 Design, build and refine a device that works within given constraints to convert one form of energy into another form of energy.

CH. PS3.4 Plan and conduct an investigation to provide evidence that the transfer of thermal energy, between components in a closed system, involves changes in energy dispersal and heat content and results in a more uniform energy distribution among the components in the system (second law of thermodynamics).

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