Curriculum Units by Fellows of the National Initiative
2016 Volume IV: Energy Sciences

Energetics of Biofuel - Investigating Alternative Energy Sources by Manufacturing Biodiesel

Curriculum Unit 16.04.04, published September 2016
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Introduction & Rationale

> “Energy and persistence conquer all things.” – Benjamin Franklin

The advent of the Industrial Revolution in 1769 forever altered our way of life and reliance on energy. Only two-hundred and fifty years ago, the world was introduced to light bulbs, steam engines and locomotives. Globally, the human population exploded as did the demand for energy. At no other time in human history have we relied on energy as we do now. Take for example one of the most sought after forms of energy, electricity. We use it to power our cellphones, computers, lights, and appliances. Today, electricity is essential for developing countries as it ensures economic growth and fosters innovation critical for technological progression. How we generate electricity varies with geopolitics, access to technology, economics, and proximity to resources. Historically we have consumed a variety of non-renewable energy resources such as coal, petroleum oil and natural gas. Today countries are expanding their energy portfolios by investing in renewable technologies that include solar, wind, biomass, tidal, and geothermal as a way to build sustainable capacity. In order to understand our current sustainable energy crisis we must ask several fundamental questions: what is energy, how much energy do we consume, what are the effects of non-sustainable energy sources and what renewable energy resources exist in the United States.

Energy is a property of an object that can be transferred to other objects or be converted into different forms. XV Energy’s inherent flexibility coupled with its conservative nature allows us to harness power to perform work. Since the Industrial Revolution, society has relied upon fossil fuels – mainly coal, natural gas and oil – to convert highly energetic hydrocarbons into heat and electricity. These stored sources of fuel were once organic matter in plants that harvested solar energy. Over millennia the organic matter transformed, through heat and pressure, into our current sources of fossil fuels. As populations have increased so too has our demand for energy.

According to data published by International Energy Agency (IEA) the yearly global consumption of energy was 143,851 TWh in 2008, with the U.S. contributing 29,014 TWh. XVI To truly grasp the scale of energy consumption, let’s look at some examples we can relate to. A single fluorescent light bulb is powered by twenty-seven watts. Remember a watt is the amount of work performed by energy per unit of time, in this case the work done is to provide light. An external air conditioner unit typically consumes 1.4 kW. If we were to install 1 billion of these air conditioners and run them all the time for an entire year, we would consume 12,264 TWh (i.e. 1.4 TW times 8760 hours per year). This would account for only about 42% of our annual consumption, which is continuing to rise to meet economic demands. Data from the IEA shows that the average energy use per person increased 10% from 1990 to 2008. XVI These energetic trends are expected to rise as emerging economies enter the world market. One of the most rapidly growing economies is China, which has doubled its energy consumption. In 2001, China consumed an average of 979.25 kg oil equivalent per person in a year, and by 2011 it surged to 2,029.36 kg oil equivalent. XVI In 2008, China consumed more total energy than the United States, primarily from coal-fired power plants. Today, China is diversifying its energy portfolio by investing in renewables such as solar, wind, and hydroelectric. Likewise, the U.S. and members of the European Union are funding development of renewable technologies and enhancing energy efficiency in existing infrastructure to reduce greenhouse gas emissions. The U.S. government has provided a variety of subsidies to companies in the hopes of developing a competitive market for renewable energy. Tremendous progress is still needed to overcome our reliance on fossil fuels and reduce emissions.

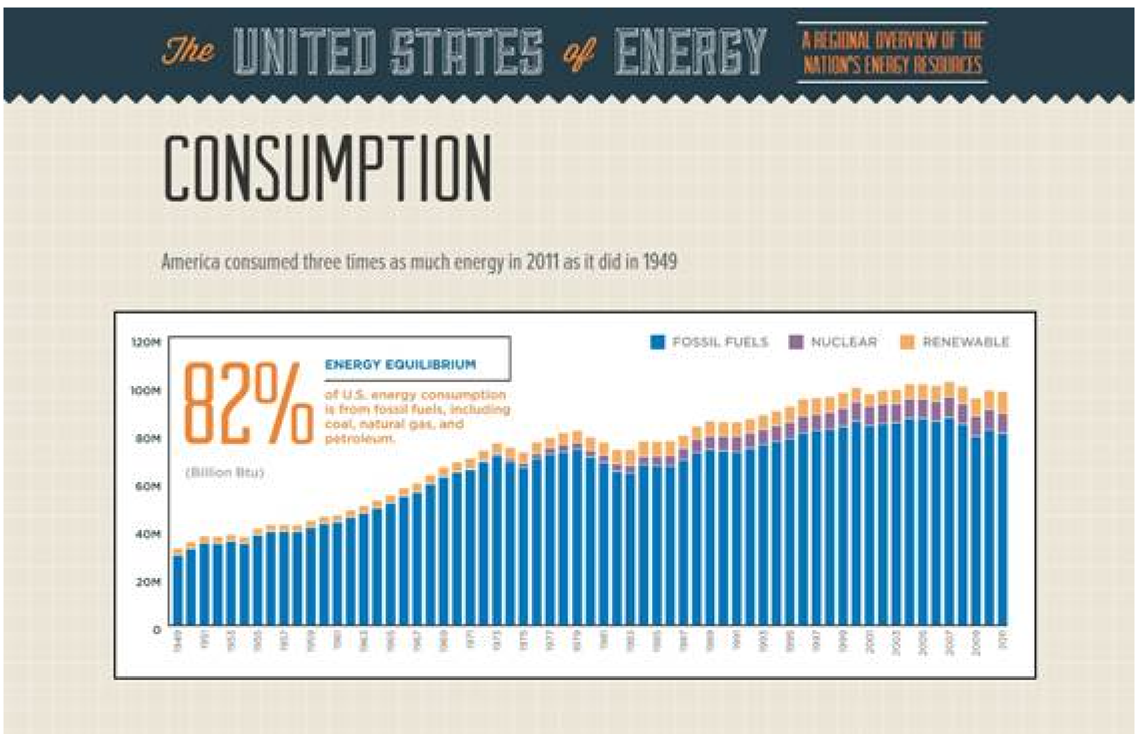

Figure 1: “The United States of Energy” created by Saxum illustrates the rapid increase in energy consumption from 1949 to 2011 in the United States.

The scale of the energy market has led to measurable impacts on the planet. In 2010, the world’s greenhouse gas emissions were approximately 9,500 million metric tons of CO_2 from fossil fuels. XII Carbon dioxide, a green-house gas, prevents the infrared spectrum from escaping Earth’s atmosphere leading to the overall warming of the global climate. The latest Intergovernmental Panel on Climate Change (IPCC) report produced several comprehensive predictive models that illustrate the dire need to cut emission levels by 40-70% before 2050. XVII Scientists estimate a global rise in temperature of approximately 2 ºC with some estimates up to 5 ºC. XVII These marginal temperature increases over a short amount of time may have disastrous consequences to national economies, food security, ecological diversity, and more importantly our children’s future. Unless active discussions and agreements between countries should arise or global consciousness takes precedent over individual needs, the future remains precarious. The G20 countries, the major contributors of carbon emissions, have tentatively agreed to reduce emission levels. XVII However, global energy consumption continues to rise as North American and Asian economies continue to grow with the complex globalized marketplace.

Globalization has inextricably linked the world together, thus making energy security and climate change an international issue. Historically, increased energy demand has led to geopolitical conflict, improved efficiencies and technological innovation. We can look back and cite several examples from that past that demonstrate this phenomenon. The invasion of Iraqi forces and occupation of Kuwait led to the Gulf War in 1990-1991, a direct result of energy security. At the time, Saddam Hussein implored OPEC to reduce overall production to increase the price of oil. As a petro state, Iraq was dependent upon the revenue of oil exports. Kuwaiti officials rejected Saddam's proposal, which inevitably led to the invasion, resulting in the Gulf War. Another example of geopolitical conflict arose when the United States provided aid to Israel in the 1973 Yom Kippur War. The U.S. supplied arms to Israel after Egypt and Syria launched a military campaign against Israel. As a response, OPEC along with other Arabic nations enacted an oil embargo against the U.S. The 1970's oil crisis led to surging prices, from $3 per barrel to $12 per barrel within a year. VII By the 1970's, U.S. oil production was already declining which further compounded the oil shortage. The regional vulnerability of the Middle East has increased domestic energy efficiency. Throughout periods of high oil prices, energy efficiency gains have manifested in a number of ways, most notably in car efficiency standards. In 1985, Congress passed a law that required cars to have a minimum level fuel efficiency to prevent future oil shocks. VII After 2008 when oil prices peaked at $136.1 per barrel, the Obama administration introduced a bill that required increased car efficiency standards from 30 mpg to 54.5 mpg by 2025. VII In addition to the investments in energy efficiencies, the U.S. has spent millions on innovations in renewable technology to reduce CO_2 emissions. The U.S. is poised to become a global leader in renewable technology due to its bountiful carbon-free resources around the country: from the untapped solar energy in the southwest, to the sprawling wind belt throughout the Midwest (Figure 2). Throughout the 1990's, California fully embraced renewable energy with numerous wind farms and solar installations. These controversial projects were funded through government subsidies after the Gulf War. The initial investment was fraught with expensive wind turbines that intermittently produced power. Technological optimization of wind energy has now become a viable alternative to fossil fuels. By 2015, California generated 12,000 GWh of wind energy, which is double the capacity 5 years ago. VII Other states are in the process of assessing their environmental assets to minimize their carbon footprint and gain energy independence. Innovations continue to emerge from the energy crisis but the environmental crisis that we face may push the limits of human innovation.

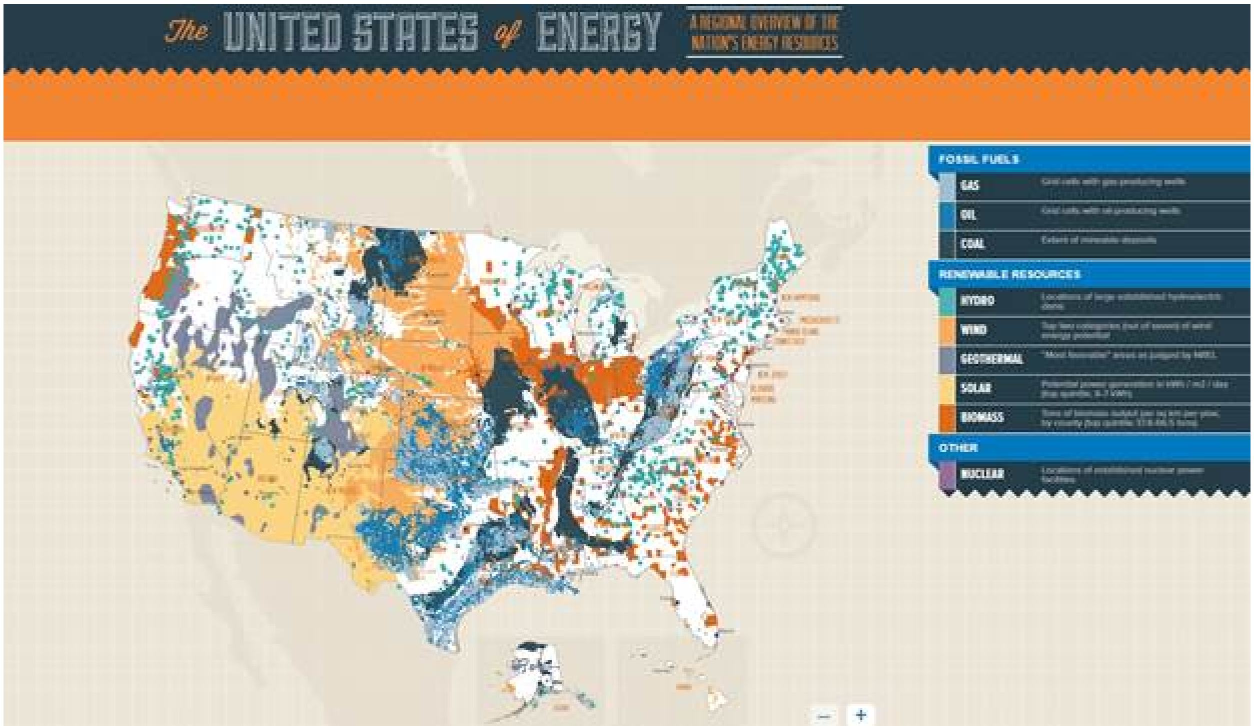

Figure 2: “The United States of Energy” created by Saxum depicts the regional energy resources within the United States.

One innovation that has become popularized by the United Sates and Brazil is biofuel energy. These energy sources are derived from biomass resources that include corn, sugarcane and switch grass for the production of ethanol. This alternative fuel source comes from the fermentation of simple sugars derived from plants. One of the highest sugar-content crops is sugarcane which is has been a staple crop produced in Brazil. Throughout the early 1970’s, Brazil was importing 85 percent of its oil. VII This came to an abrupt halt with the 1973 oil crisis, when the price of oil tripled. VII As a result, the Brazilian government launched a Pro-Alcohol program to manufacture ethanol from the surplus of sugarcane crops. The program was so successful that Brazilians now drive fuel flex cars and motorcycles that allow them to alternate between traditional petroleum based products and ethanol. In 2010, 6.9 billion gallons of ethanol fuel were produced. VII In the United States, innovation was prompted with the 2008 recession, when oil prices surged, forcing many to be resourceful. Small business owners began harvesting used vegetable oil from restaurants to produce biodiesel. This alternative fuel source is manufactured through a process called transesterification, where the glycerin is separated from the fatty acids. This application is a rather simple process but is limited by reliable sources of surplus vegetable oil. Innovations like this coupled with optimizing efficiency will be imperative for cutting emission and solving the energy crisis in the future. However, we must commit to our investments for the future, even when prices of oil remain low.

In this unit, we will explore how biodiesel plays a role in alternative energies and integrate fundamental energetic principles to inform our students about the limitations of energy transformation. The energy and environmental crisis of the 21st century is vital for students to comprehend and participate in. Policies of today will directly impact their future, as they inherit a globalized economy that will require diplomatic compromise and international collaboration. This unit introduces learners to the unsustainable energy crisis while simultaneously reinforcing the physical concepts associated with energy using biodiesel as a vector of inquiry. It is imperative that students develop strong foundational skills in physical science so that future innovations can be realized.

School Demographics

Ballou High School is a low-income, low-performing school with approximately 678 African American students, located in the southeast of Washington DC. Here gun violence and drug trafficking are prevalent, fueled by gang activity. Violence is a way of life in southeast DC and many students experience emotional and physical trauma, often leading to volatile behavior in the classroom. Many students struggle to get to school due to trouble at home or with the law. As a result, truancy is high at Ballou High School, with approximately 68% (32% absent) in seat-attendance. In addition, high occurrences of teen pregnancy lead to further time away from school. Students who lack consistency often fall behind in class and cause behavioral disruption further impeding potential educational gains. Students typically score below grade level in math and reading. Initiatives have been implemented to curtail these trends; however, it will take several years to see academic gains. The students at Ballou High School learn best with a positive, structured, dynamic classroom, with hands-on activities coupled with praise or rewards. Many students have not seen academic success and yearn to learn. The biodiesel project will excite many students about the possibilities of physics and finding a voice within the community. Relating the material to what interests them will allow better buy-in overall. This will fuel students to meet the high academic expectation set at the school and in the classroom. Students will get opportunities to collaborate and communicate their results to the community. In addition, they will have a valuable skill that would look good for possible biotech employment. When preparing students for the 21st century it is essential to introduce topics as they pertain to the community directly, in addition to the global impacts. The project is but a pebble in an ocean but its implementation may have rippling effects across that school and community.

Content Objectives

This unit is designed for high school students to investigate the energetics involved in producing biofuel, specifically biodiesel from cafeteria vegetable oil. These inquiry-based and immersive experiences will allow students to actively participate in developing ideas about the global energy crisis while reinforcing concepts about physics. Topics will follow Next Generation Science Standards (NGSS) as well as District of Columbia Public School's (DCPS) scope and sequence. The unit has a number of key objectives that can be adapted. The following objectives will be addressed throughout the nine-week unit: 1) What is energy? How is it defined and measured? 2) How is energy conservation observed in the manufacturing of biodiesel? 3) What types of energy transformations occur during the production and consumption of biodiesel? 4) What are the steps for manufacturing biodiesel? 5) How efficient is biodiesel compared to other renewables? 6) Is biodiesel a viable renewable resource? Why or why not?

Content Background

Energy

What is energy?

The classic definition of energy is the capacity to do work when in actuality it is a property of an object that can be transferred to other objects or be converted into different forms. XV Energy is the foundation of all life and matter in the universe. Every living creature contains different amounts of energy from a single cell organism floating in the ocean to a small child playing on a playground. Everything we do is linked to the transformation of energy. Energy is dynamic as in the case of our bodies, when we process food, converting chemical energy stored in the food to mechanical energy as we walk from our office to our cars. Physicists classify energy into two categories, kinetic energy and potential energy. Kinetic is associated with motion, examples include the mechanical energy from a car engine, the electrical energy from a lightbulb or the electromagnetic radiation emitted from the sun. Conversely, potential is energy associated with a specific position in time and space. This may appear in the form of gravitation potential energy at the peak of a roller coaster. The concept of energy was first documented by the Greeks with a philosophical perspective that we will not explore in this unit; however, this is important to note as it had a profound influence on future scholars. The first conceptual understanding of energy was proposed by Gottfried Leibniz in the late 1600's, who coined the term *vis viva*, known as living force. XVIII His ideas, like so many at the time, were dismissed by the scientific community. The idea of kinetic energy would not be revisited for another one hundred and fifty years by Thomas Young. In 1807, Young defined the modern term "energy" which would later provide the foundation for the description of kinetic energy and potential energy. These works would eventually lead to the discovery of conservation of energy. Recognizing energy as a fundamental principle of physics led the establishment of the joule as the standard scientific unit of measure for energy. The joule is named after the English physicist James Prescott Joule (1818-1889) who determined the mechanical equivalent of heat. XVIII

Types of energy

Energy exists in many forms including, thermal, electric, nuclear, chemical, and mechanical. These types of energies can be transformed through passive and active processes depending on the associated energetic costs. The dynamic nature of energy allows us to utilize this fundamental principle of the physics in all manners of work. Take for instances the movement of a ball down a hill; the position of the ball in relation to the Earth causes the potential energy to be converted to kinetic energy lending itself the ability to perform work. Energy and the laws that govern energy transformation have allowed us to generate electricity from a river, build impossibly high skyscrapers and even send a man to the moon. Some types of energy lend themselves more advantageous than others depending on the work required. It is important to grasp the variety of energy types since some types of energy transformations can be multifaceted. The production of biofuel and its subsequent utilization is a complex series of energy transformations. Thus, we must begin to understand energy by recognizing the various types that have been circumscribed. (Note the types of energy denoted are unit specific with regards to biodiesel; thus, nuclear energy and elastic energy will not be actively discussed during the unit).

Kinetic Energy (KE) – Energy is associated with motion, as the universe is in constant motion. A student sitting at his or her desk is actually moving 1,000 miles per hour around the sun, even though he/she may appear to be not moving. When an object is moving it is said to possess kinetic energy (KE). Thus, kinetic energy is the energy of motion, which can be applied to either vertical or horizontal axes. Other examples of kinetic energy include a car traveling along a highway, a ball rolling down a hill, or the subtle vibration of molecules, all of which possess energy that can be used to perform work. Kinetic energy is inherently a scalar quantity, meaning that the measure is void of a direction. VIII Below is the formula for kinetic energy, which demonstrates that kinetic energy is directly proportional to the mass (m) of an object and its velocity (v). In other words, if two cars traveling at the same speeds but different masses collide, the car with the greater mass will contain more kinetic energy. This principle of kinetic energy will be introduced when designing our mouse-trap cars at the beginning of the energy unit. In addition, kinetic energy will play a pivotal role in optimizing our biodiesel blends for our diesel engine's performance and efficiency.

$KE = ½ mv^2$

Potential Energy (PE) – Energy can be stored in a variety of different forms, which we often refer to as potential energy. This type of energy often gets misconstrued as just stored energy; however, the magnitude of PE is directly related to the position of an object in relation to other objects or forces. For example, a child shooting a slingshot uses the stored energy in the elastic band to shoot a projectile. The farther the elastic band is pulled back the greater the potential energy. The most popularized form of potential energy is gravitational potential energy (PE_{grav}). PE_{grav} is energy possessed by an object based on its position within a gravitational field. As an object is raised above the surface of the Earth, it increases its PE_{grav} since gravity (g) will act upon it. Thus, the greater the height (h) of the object the greater the potential acceleration due to gravity. In addition, the mass (m) of the object is directly related to its potential energy as seen with kinetic energy. VIII

$PE_{grav} = mgh$

Chemical Energy (CE) – Potential energy is also stored within bonds of compounds, which is referred to as chemical energy. For example, the stored energy in a battery enables us to power a flashlight, converting chemical energy to electrical energy. During a chemical reaction, energy is released or absorbed in the form of heat or mechanical energy, depending on the type of reaction. Reactions that release energy are called exothermic, whereas those that require energy are endothermic. XVIII Throughout the unit students will utilize chemical energy in a series of reactions, from the production of the biodiesel to the combustion inside the engine. During combustion, oxygen reacts with another compound, in our case a hydrocarbon in the form of biodiesel, to produce heat, light, and mechanical energy. The chemical composition of the various blends of biodiesel will directly impact the total mechanical energy produced and thus the overall performance of the engine. These will be essential concepts to master when students analyze the energetics associated with traditional petroleum fuel sources and biodiesel.

Mechanical Energy (ME) – The movement of a car is the result from a series of moving parts that possess the ability to perform work also known as mechanical energy. From the pistons in the engine compressing gas to the wheel axles applying sufficient torque, all of which perform work that enables motion. Thus, mechanical energy can be thought of as the energy acquired by the object upon which work is done. This type of energy can either be potential or kinetic in nature; however, during the unit we will primarily focus on the kinetic parts within a diesel engine. VIII The total mechanical energy (TME) is the sum of the potential energy (PE) and kinetic energy (KE). The TME is the energy possessed by an object due to its motion or relative position with stored energy. This formula will be introduced in conjunction with the principle of conservation of energy, as there are many parallels to draw from.

$TME = PE + KE$

Electric Energy (EE) – The electrical current generated from an alternator provides the power to all electronics within a car in the form of electrical energy. This type of energy is one of the most highly sought after due to the demand from power companies and digital devices. Electrical energy is simply the movement of electrical charge. Two main sources of electricity are from the chemical energy within a batteries and the kinetic energy from turbines. Both of which establish an electric current along a gradient to generate electrical energy. Electric current is measured in amperes. However, the total electrical energy (E) is determined by the amount of charge (Q) and the potential difference also known as voltage (V). The greater the electrical charge the greater the overall electrical potential of a system. This will be investigated in more detail following the completion of this unit. Students should be able to grasp the concept of electrical energy with regards to energy transformation within the context of our diesel engine.

$E = QV$

Thermal Energy (TE) – Thermal energy results in the production of heat, which has limitations on how it can be converted to perform useful work. Every energy transformation performed within a car causes heat to be generated; this reduces the overall efficiency and ultimately our ability to maximize work. When thermal energy is combined with another substance to produce a temperature differential, work may be performed. Students must understand that energy is not lost but converted into various forms that may or may not be useful for work. The relationship between heat and temperature will be described and explored in a supplemental inquiry experiment. For the purposes of this unit, it is important to recognize thermal energy and account for it when discussing energy transformations.

Conservation of energy

One of the fundamental concepts of modern physics is the law of conservation of energy, which states that the total energy of an isolated system remains constant and conserved over time. XI In other words, energy can neither be created nor destroyed. This idea of energy conservation is fundamental in designing cars, power plants and heating units. When energy is used it is not lost; rather it gets converted into other forms of energy. Energy is always conserved; however, its usefulness is not. This is a fundamental principle that will be reinforced throughout the unit. In cars, the energy in fuel is highly concentrated allowing each gallon of gasoline or diesel fuel to be easily accessible. Once the fuel is burned in the engines it gets converted into thermal energy and mechanical energy. XV The mechanical energy is used to perform useful work, such as moving people from one place to another, whereas the thermal energy radiates from the engine block producing heat. Even the mechanical energy gets transformed into heat through the friction of moving parts or by pushing air molecules out of the way. XV

Combustion

What is combustion?

The first use of combustion was the discovery of fire, which provided heat and light to proto-man. Today we have harnessed the power of combustion by transforming the chemical energy to provide home heating, develop projectile weaponry and power our car's engines. Combustion is an exothermic redox reaction that occurs when a substance rapidly combines with oxygen (O_2). XV At the molecular level, chemical bonds are broken and then reassembled; the rearrangement of bonds may absorb or release energy. When an organic substance undergoes combustion the result is carbon dioxide (CO_2), water (H_2O), and heat (thermal energy); this may vary slightly depending on the chemical composition of the organic molecules. XV The first step in combustion requires the chemical bonds between the organic compounds to break down; this occurs through an ignition source. Upon reaction with oxygen, the chemical energy stored in the bonds of the organic molecules is released resulting in light and heat. The amount of energy released is dependent on the ratio between hydrogen and carbon in the organic molecule. Greater concentrations of hydrogen atoms per unit of carbon will release substantially more energy during the oxidation reaction. XV Coal and petroleum have a high hydrogen to carbon ratio which allows them to be ideal candidates for powering cars. Once the production of biodiesel has been optimized students will measure the energy output from various blends of biofuel and compare them to traditional petroleum products. Thus, understanding this redox reaction will be essential for our unit.

Internal combustion engine

Modern vehicles utilize an internal combustion engine, which harnesses the chemical energy from hydrocarbons and transforms it into mechanical energy to perform work. The exergonic reaction of combustion drives pistons in a linear motion within a metal cylinder that turns a crankshaft. IV The torque from the crankshaft causes the wheels to turn propelling the car forward. The internal combustion engine has a rich history dating back to 1680, which will be discussed in some detail during the unit to provide context.

An astronomer by the name of Christiaan Huygens designed the first internal combustion engine powered by gunpowder in 1680; however, a prototype was never built. IV It would take another hundred years before Samuel Brown modified a steam engine to burn gasoline to power a carriage in 1826. This would be the inspiration for future ventures in automobile design that would further progress the development of the internal combustion engine. No effective gasoline-powered engine was developed until J. J. Etienne Lenoir built a double-acting, spark-ignition engine in 1859. IV The German engineer, Nikolaus August Otto, patented the first four-stroke engine in 1876, leading to the modern internal combustion engine. IV This led to a greater efficiency within the engine due to the power-to-weight ratio. Today the majority of automobiles utilize variations of this engine design.

The four-stroke cycle was instrumental in commercializing automobiles. As the name implies it utilizes a series of four steps to complete a single cycle, these include: induction/intake stroke, compression stroke, combustion/power stroke and exhaust stroke. During the intake stroke the piston moves downwards to maximize the volume of allowable air, through valves, in the combustion chamber. Next is the compression stroke, valves are shunted as the piston drives upwards reducing the volume within the combustion chamber. As a result the pressure, temperature and density increase allowing for ignition. IV The pressure generated from the combustion pushes the piston downward, generating work creating the power stroke. The final step expels the leftover gas through the exhaust valve and prepares for the intake valve to open. This ingenious technology optimizes the gas laws and thermodynamic principles to generate work, as illustrated in Figure 3. This internal combustion engine along with the four-stroke cycle will be discussed thoroughly as it is central to understanding energy transformations within a car’s engine and paramount to determining biofuel efficiencies. IV

Biofuels

Biodiesel

Biodiesel has a rich history that dates back to the late 1800’s when Rudolf Diesel conducted his first tests in Germany to develop the infamous motor engine. Early models of the motor engine ran on peanut oil and vegetable oil. “Biodiesel is a domestically produced, renewable fuel that can be manufactured from new and used vegetable oils, animal fats, and recycled restaurant grease”. V A number of biodiesel blends are used to accommodate transportation. These include: B100 (pure biodiesel), B20 (20% biodiesel, 80% petroleum) B5 (5% biodiesel, 95% petroleum) and B2 (2% biodiesel, 98% petroleum). V During the production phase of our biodiesel unit students will distill two different types of biodiesel blends to analyze them. Ballou High School is fortunate enough to have access to an automotive department and we will be using the spare cars to test our biofuels. If access to spare cars is limited, biodiesel can be used in vehicles manufactured after 1993 but it is best to check with the equipment manufacture prior to use. Blends above B5 may cause high levels of fuel to accumulate in the engine lubricant, which will affect overall performance, so be sure the car is non-essential. In addition, biodiesel should be avoided at freezing temperatures as the fuel tends to solidify rendering the engine inoperable. This should only affect communities in remote regions with extreme winters but be mindful if you decide to proceed with the project.

The manufacturing of biodiesel is a relatively simple but labor-intensive process. Biodiesel is commonly produced through a chemical process, known as transesterification, where an alcohol is swapped with a carbon group from an ester. V During the first stage of production, alcohol and oil are mixed with a catalyst to yield glycerin and biodiesel. The catalyst used is potassium hydroxide along with a methanol alcohol base. V There are other catalysts and alcohols that can manufacture biodiesel; these can be obtained in the student and teacher resources. Once methoxide is added to the vegetable oil, slowly increase the temperature to 55 ºC for 45 minutes; this results in formation of glycerin and biodiesel. XIV Let the mixture settle for approximately 48 hours before processing. The biodiesel should become clear once separated from the dense molecules of glycerin. The longer the mixture settles the fewer impurities within the biodiesel. Isolate the biodiesel and begin washing with water; this removes the remaining glycerin and methanol from the biodiesel. Before use or testing, the remaining water must be evaporated through a settle-drying process. XIV Areas of high humidity may take a long time for the water to evaporate, so plan accordingly. The final stage of biodiesel production is the testing; this ensures the overall quality and standard. Our unit will compare the energy output of biodiesel with traditional petroleum fuel sources. This will be accomplished using the heat capacity of water to output the total energy released from identical volumes of fuel. In addition, engine efficiency will be investigated when we collaborate with the automotive department. If time allows, the unit may explore the energetics of other biofuels including ethanol and cellulosic ethanol.

Economic Implications of Biofuels

The viability of biofuels depends on a variety of factors including availability of source material, price of petroleum and demand of the product.VI Biofuels may prove advantageous to companies who produce excess biomass or oil. However, the tonnage required for mass production inhibits wide spread growth and the problem of intermittency still plagues the industry. Unsurprisingly, the price of oil has directly inhibited future ventures in biofuel production since oil is a much cheaper and more efficient fuel source. However, the United States has seen production of biodiesel jump from 209 million gallons in 2005 to 1.13 billion gallons in 2011.VI This has led to increased employment opportunities within the energy sector, centralized primarily in rural areas of the country. Although biofuel will only marginally impact the energy market, it offers consumers an alternative product. In addition, biodiesel can be manufactured at local levels, which provides benefits at a smaller scale. This unit will discuss the implications of biofuel after measuring the energy from the fuel sources. This will allow students to become more informed and participate in future energy policy proposals.

Environmental Effects and Tradeoffs of Biofuels

Biofuels like petroleum products have their own environmental costs. Each processing stage uses nonrenewable resources and generates emissions in their own right. Emissions are affected by a variety of factors including feedstock, production facility, and management practices. VI Greenhouse gas emissions from biofuel production, transportation, and use include carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4). VI The use of biofuels in combustion engines using low-level blends results in lower CO emissions but higher emission in benzene, non-methane organic gas, and non-methane hydrocarbons. Higher blends have lower emission levels of nitrous oxides, non-methane hydrocarbons, and benzene with higher emission of acetaldehyde and formaldehyde.VI Research is still required to determine the environmental benefits and costs of biofuel usage. Policy and technology may prompt greater efficiency with lower emission rates of greenhouse gasses.

Teaching Strategies

Blended and Project-based Learning

The unit will concentrate heavily on a blended learning and project-based approach that incorporates station rotation with maker-space, mini labs, reading comprehension and critical skill development in independent groups. Students will be expected to take Cornell Notes during the lecture portion of class with periodic informal assessments. During the subsequent class period, students will apply and practice concepts introduced in the lecture series through station rotation. The number of stations may vary based on student population and dynamics.

The idea of station rotations is for students to maximize their learning and to develop skills of independent problem solving. The system is designed to incorporate different modes of learning. Groups will be organized based on student strengths and weaknesses (i.e., kinetic, auditory, and visual) when opportunity should arise.

Literacy and Reading Comprehension

Students will read from a variety of scientific articles about key concepts related to the week's content. The scientific articles will cover a range of Lexile levels to accommodate all readers. The primary task will be for students to annotate (i.e., highlight unknown terms, identify key ideas and summarize in 5-6 sentences) one of the articles and link it to the unit's content area in their own words. Ballou High School (BHS) students struggle with the fundamental skills of reading and writing, a majority of the student population is below grade level. This station will allow them to develop these skills while simultaneously reinforcing content from the week.

Applied Mini Labs or Maker-Space

Students will practice inquiry learning through applied activities. These may include maker-spaces (i.e., building prototypes of soapbox cars), applied mini lab (i.e., measuring energy output of different types of fuels), or Physics Education Technology (PhET) online simulations. PhET interactive simulations are targeted towards math and science from the University of Colorado. The simulations range in topic from energetics to fractions and are sorted by grade level II. PhET has shown to be highly effective when it was piloted in the classroom last year. The maker-space will allow student build-time for various projects assigned throughout the year. During the motion unit, students will be designing soapbox cars, utilizing the principles of drag, friction, and force. The applied mini-labs will consist of brief experiments or exploratory activities that students must perform within a 20 minute timeframe. In the energy unit, students will compare various blends of biodiesel by color, viscosity, and overall composition. The students of BHS excel at hands-on learning; students tend to be visual and kinetic learners. These activities will facilitate successful exploration of content and how it applies to career opportunities.

Critical Thinking Skill Development

Students will be tasked with solving mathematical word problems from the text book that practice the use of critical formulas or concepts introduced. Student will be required to show all work for full credit and document their meta-cognitive thinking. Problems will progressively become more difficult and will require mastery over concepts. This activity is designed to challenge the students individually and as a group; many students become frustrated when answers are not apparent. This type of deep thinking that provides resistance will build stamina in the classroom for more in-depth projects to be introduced. The purpose of science is not to get the “right” answer but to think critically about the material so that better questions can be asked.

Classroom Activities

Supplemental Inquiry Investigations

Mouse-Trap Vehicle (Energy Transformation)

Students will work collaboratively to design and test a mouse-trap powered vehicle. This activity will ask student to carry out research, acquire the materials, perform tests and explain how the car demonstrates energy transformation. Students should have prior knowledge that energy is neither created nor destroyed and be able to differentiate between kinetic and potential energy. The mouse-trap vehicle generates kinetic energy from the stored energy within the spring of the mouse trap. Energy stored in the spring will be transferred to the wheels of the mouse-trap vehicle generating a mechanical force that drives the vehicle forward. A variety of designs will be shown to students; however, the design efficiencies will not be revealed until after tests are carried out. The activity will take six class periods and will require students to pass two-checkpoints prior to testing. The overall design and material list must be approved by the teacher to ensure authenticity. Students will collect multiple trials of time and distance data to determine the average speed of the mouse-trap vehicle. An opportunity for redesign will be given to students; however, they must justify the redesign, using physical concepts.

Energy transformation and energy conservation are fundamental concepts in engineering and science. This will serve as a primer prior to biodiesel production. It will be critical for students to understand the iterative steps of energy transformation throughout manufacturing of biodiesel.

Liquid Layering (Density)

Students will perform a liquid density lab using honey, corn syrup, Dawn dish soap, milk, water, vegetable oil and rubbing alcohol. Density is a measure of how much mass is contained in a given unit of volume (density = mass / volume). If the mass (weight) of an object increases but the volume stays the same then the density of that object will increase proportionally. Students will investigate this fundamental principle by measuring the mass of each liquid using a scale. Every group will be given 25 mL of each substance and asked to order the liquids densest to least dense. They will test their hypotheses by sequentially pouring the liquids in a beaker and recording the results. An extension will be provided to groups that use their time efficiently and finish within the allotted time. Student will be presented with 5 objects of varying sizes, weights, and volumes. The students will be tasked with predicting where (which layer) the object will settle within based in its estimated density.

These principles are an essential component to the biodiesel production process and will serve to refine the concept of density, mass, weight, and volume. Once the catalyst mixes homogenously with the vegetable oil and methanol, the biodiesel will naturally separate from the dense glycerol. This will be instrumental in the students understanding of how and why the process works.

Measuring Energy (Energy Conservation)

A variety of fuel sources, including the biodiesel produced from the vegetable oil out of the cafeteria, will be collected to test the energetics of each. Students will measure the net energy by taking the temperature differential from water. Approximately 10 mL of liquid fuel will undergo combustion in an ethanol wick burner. A beaker, filled with 100 mL of water will be placed at the on top of the burner. During the experiment students will record the initial temperature and final temperature along with 30 second increment readings. The net energy of each source of fuel will be estimated using the specific heat of water along with the change in temperature. Students will be asked how the principle of conservation of energy is observed.

Biodiesel Energetics

The biodiesel unit with its nuances and complexities will be divided into three phases to promote student retention and depth of content. Students will first be introduced to the concept of energy and energy types through various hands-on demonstrations and inquiry experiments. In addition, the culminating project of comparing the energetics of biofuel with traditional petroleum fuels will be presented to the students, accompanied by a calendar with a deadline and the project rubric. These will also be available online at the classroom website at www.ballouhsphysics.info. Students will then investigate the phenomenon of conservation of energy by performing phase change experiments with water. These concepts and themes will be repeatedly interwoven throughout the biofuel project to substantiate their importance and application.

Phase I (Collection)

The collection of the vegetable oil will happen outside of the classroom to maximize instruction time. Students may be selected, as a reward, to accompany the teacher on specific dates. The vegetable oil will likely come from two sources: the first being the school cafeteria and the other from a local restaurant. The school district policy and outside vendor contracting may prohibit the transfer of waste oil for classroom use due to liability reasons. These issues will be explored prior to the introduction of the project. The use of the school's cafeteria oil would have created additional buy-in with the students but this does not inhibit the project in any way as an outside source of vegetable oil has already been secured. Approximately a gallon of vegetable oil will be collected at a time. This will allow for enough to optimize the biodiesel process and minimize school impact. The waste oil can be rather pungent and messy. To minimize impact, batches will be small, initially. If enthusiasm is generated between departments and grade levels the scale of the operation may grow.

Phase II (Production)

The production of biodiesel will undergo several iterations to maximize student participation. The production process is rather time sensitive and requires mastery of the stages for quality yields. Once optimization has occurred, student protocols will be developed for instructional references and recording data. Students will begin their production of biodiesel by measuring the pH levels of vegetable oil sources to determine variability and ultimately the amount of catalyst to use with the transesterification reaction. The significance of this will be discussed in class along with reasons for why pH levels fluctuate. A demonstration of the transesterification reaction will be shown in class but students will not participate since many lack laboratory experience and the danger that methoxide poses with dermal contact. Once the methoxide is added to the vegetable oil it will be set at 55 ºC and left to settle until the next class period. Students will separate and measure the amount of glycerin and biodiesel before they begin washing the biodiesel. Once the biodiesel is washed and purified it will be left to dry before the analysis phase.

Phase III (Analysis)

The biodiesel will undergo several analyses and be compared with petroleum fuel. The first investigation will ask students to calculate the amount of energy in 10 mL of biodiesel using the heat capacity of water. Students will measure the initial temperature of a 100 mL glass of water and the final temperature once the fuel source is spent. Students will use portions of the biofuel to determine if it will start a diesel engine and develop hypotheses using their knowledge of how a four-stroke engine works. In addition, various blends of biodiesel will be manufactured outside the classroom where students will compare viscosity, color, and energy. As a culminating assessment students will type up a lab report that incorporates the manufacturing of biodiesel along with a key finding from the experiments performed during the analysis phase. To celebrate student success, an open house will be scheduled to invite community leaders and district officials to learn about the findings. This will allow students to see the application of science and how the principles taught in class have real-world applications.

Teacher and Student Resources

For supplemental information that will be utilized at varying degrees throughout the biodiesel unit please review the following. A deactivated link is provided along with a summary of the resource.

Khan Academy

Khan Academy is a non-profit educational organization that provides free lectures in the form of YouTube videos. There are practice exercises along with a personalized dashboard if students register on the website. This resource is helpful for students that require supplemental learning or need to make up work due to absences. (https://www.khanacademy.org)

Physics classroom

Physics classroom is a free online resource for beginning students and teachers. There are a number of animations, problem sets, and tutorials that supplement classroom content. The website provides guidance to targeted misunderstandings and strengthens students’ critical thinking skills with multi-tiered word problems. (http://www.physicsclassroom.com)

Ballou HS Physics Classroom Website

The Ballou HS classroom website will serve as a depository for notes, problem sets, and external supplemental resources throughout the year. It is designed to highlight content specific to the students of Ballou but also serves as a resource for other teachers that would like to modify the protocol from the biofuel unit. The website is currently live but under construction; look for frequent updates in the future. (http://www.ballouhsphysics.info)

Biodiesel Production Manual

Biodiesel production can be modified and customized in a number of different ways. The protocol provided by MIT is well written and organized for those looking to get started. Test runs will be carried out in the fall to optimize the protocol and master the nuances associated with vegetable oil sources. (https://biology.mit.edu/sites/default/files/Make_Biodiesel.pdf)

Endnotes

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XVII IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

XVIII Hsu, Tom. *Foundations of Physics*. Peabody, MA: CPO Science, 2004.

Appendix

NGSS Standard Integration

The unit will incorporate standards from the Next Generation Science Standards (NGSS) in Unit 3 and 4 under the Energy and Motion. The focus will be primarily on energy and energy conservation.

Disciplinary Core Ideas

Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved even as, within the system, energy is continually transferred from on object to another and between its various possible forms. (HS-PS3-1) (HS-PS3-2) I

Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. (HS-PS3-1) I

Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g., relative positions of charged particles, compressions of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior. (HS-PS3-1) I

Crosscutting Concepts

When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models. (HS-PS3-4) I

Science & Engineering Practices

Plan and conduct an investigation individually or collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. (HS-PS3-4) I