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Analyzing Energy Efficiency Through Energy Transformations

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> "If you want to find the secrets of the universe, think in terms of energy, frequency, and vibration."
>
> – Nikola Tesla

Introduction (Overview)

The existence of work is predicated on the law of conservation of energy and harnessing the necessary energy transformations. Our modern electrical infrastructure transforms a myriad of energy sources (i.e., fossil fuel, solar, wind, tidal) into an electric current to provide our 21st-century amenities such as air conditioning, home heating, entertainment center, and lighting. Discussions surrounding the complexities of sustainable energy and energy consumption often lack clarity or reference to the law of conservation of energy and the physical constraints that govern energy efficiency. Students frequently struggle with energy due to its dynamic and obscure nature coupled with the forms and types it encompasses. Students often lack the necessary data or observable phenomena to verify the conservative nature of energy. This unit seeks to provide opportunities for students to further their depth of knowledge on the application of energy transformations as it pertains to observable phenomena by examining common electronic devices and discussing the current state of the United States electrical grid with regards to our energy portfolio.

Demographics

I serve as the 11th-grade academy Physics science teacher at Woodrow Wilson High School. Woodrow Wilson High School is a relatively high-performing school in Washington, DC that consists of approximately 1,800 students. The diverse student body presents challenges for instructional delivery because of persistent achievement gaps within the school. Students have historically tested below grade level in mathematics with only 22% of students meeting academic expectations. The socioeconomic issues associated with urban schools are still present (i.e., in-seat attendance, assignment completion rate, etc.). The student body is often segregated due to the number of advance placements classes offered coupled with minimal opportunities for remediation throughout the year. The two-feeder schools for Woodrow Wilson High School are Deal Middle School and Hardy Middle School which represent two different socioeconomic populations in DC. The physics department has struggled to remain stable due to the transient nature of the district. After four years of teaching in the District of Columbia Public School (DCPS), I have learned that students respond best to a positive, dynamic classroom, with hands-on activities. The more the student understands the content's relevance, the more likely they are to gain a greater depth of knowledge. This unit will address the enigmatic principle of energy and energy efficiency with regards to electrical devices and the status of the U.S. electrical grid by investigating energy transformations.

Objectives

This 3 to 4-week unit attempts to enhance students' content mastery and analytical skills by examining common phenomenon (i.e., cellphone, combustion engine, light-emitting diode (LED) lights) that undergo a myriad of energy transformations to perform a specific function. Students will compare the net heat output of an LED light and incandescent bulb using an infrared thermometer over a period of 10 minutes using principles from thermodynamics and energetics. In addition, students will analyze their dataset to determine the efficiency differential between the two devices. The forms and types of energy have constraints with regards to their utility with current technologies which will be discussed as students delve deeper in the evaluation phase of the unit. Throughout the unit, we will investigate the underlying principles that allow electronic devices to be highly efficient by anchoring discussions to the conservative nature of energy and accounting for the number of energy transformations and pathways undergone by the device. The culminating activity will ask students to deconstruct the energy transformations in household devices and compare energy efficiency. Students will evaluate the work of each other to determine the most efficient and inefficient devices. It is my hope that students will gain a deeper understanding of energy efficiency by mastering energy transformations and the governing principle(s) with regards to conservation of energy.

Unit Content

Historical context of energy

The abstract nature of energy dates to ancient Greece, where Aristotle coined the term *energia*, in his publication, *Metaphysics* (384-322 B.C.E). Philosophers noted that every object's existence was maintained by its inherent force, *energia*.[1] Through careful observations and thought experiments *energia* became associated with an object's ability to move, perform work or generate power.[1] Energy was thought to be a living force, *vis viva*, due to its relationship with motion. After careful observations with elastic collisions, Gottfried Wilhem Leibniz defined energy as the product of an object's mass and its velocity squared.[2]

Although the mechanisms associated with conservation of energy were not clearly defined, the relationship between energy and motion was clearly observed along with an object's mass. It was not until the early 1800's that the modern concept of energy was proposed by Thomas Young. [2]

Further experimentation with heat and engine efficiency led to energy being quantified and refined existing knowledge to develop novel technologies during the late 1800's. James Prescott Joule's (1818-1889) scientific work led to the discovery of equivalence of heat by determining the amount of energy needed to raise one gram of water by one Kelvin. [3] Other noteworthy works include Nicolas Leonard Sadi Carnot, who determined the maximum efficiency of heat engines. This work ultimately led to the refinement of steam engines and the establishment of entropy. German theoretical physicist Rudolf Clausius (1822-1888) coined the term "entropy" and along with Lord Kelvin established the second law of thermodynamics. [3]

The Industrial Revolution facilitated the synergy between technological innovation and scientific discovery. No time in history had mankind made such far-reaching advancements that would forever change society. This all became possible due to our understanding of energy and its conservative nature. However, the abstract nature of energy still lacks clarity, though its importance to global economies and cosmic understanding cannot be understated. Presently, the definition of energy is the capacity for doing work, an obscure descriptor to say the least.

Energy Nomenclature

Energy can be classified as a function of motion, position within a field, or radiation. The current schema divides energy into two forms, kinetic and potential. The energy that an object possesses due to its relative motion is kinetic energy. The amount of kinetic energy generated by an object is a function of the object's mass and velocity. Conversely, potential energy is the amount of energy stored within an object, due to its position, state, or arrangement. [4] The factors involved with determining the overall potential energy depends on the type of potential energy an object possesses. A total of fourteen energy types are recognized these include; mechanical, electric, magnetic, gravitational, chemical, ionization, nuclear, chromodynamic, elastic, mechanical wave, sound wave, radiant, rest, and thermal. [4] The scope of this unit will only focus on approximately six of the recognized types.

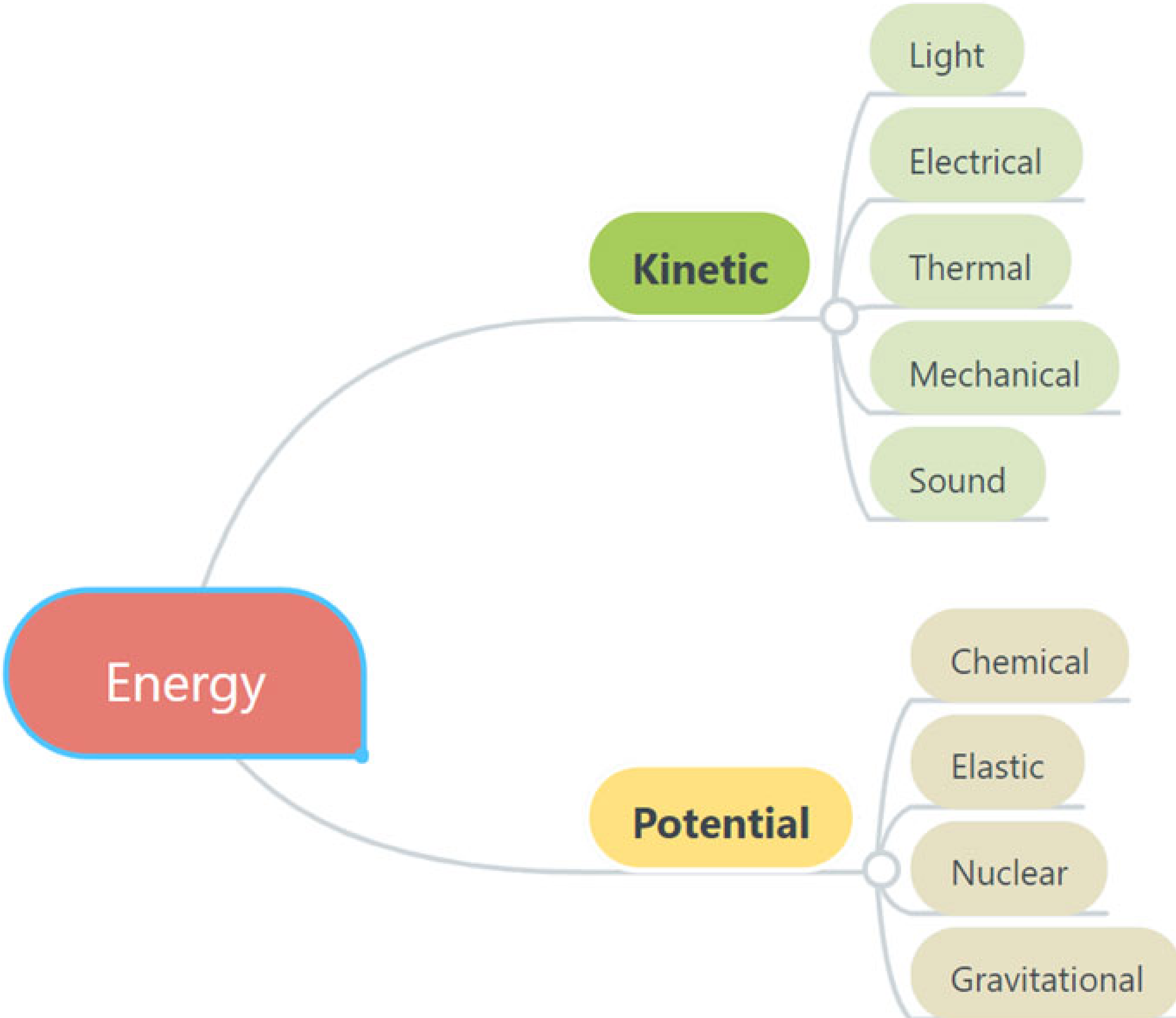


Figure 1. Illustrates a schema for energy classification.

Energy Transformation Examples

The law of conservation of energy states that energy can neither be created or destroyed; however, energy can be transformed from one type to another. This property of energy allows us to utilize forms of energy from sources other than the form used to perform work. Prior to the industrial revolution, the world's energy demands relied on whale oil for lighting, wood for heat, wind for ocean navigation. [5] The discovery of fossil fuels launched the current energy network that spurred telecommunication and the automotive industry. We will examine a series of energy transformations from simple one-step transformations to complex multi-step energy pathways with an emphasis on combustion.

Controlled Combustion (Fire)

Our capacity to utilize energy has always relied on the available technology. Our first technological achievement as a species occurred over 700,000 years ago with the application of controlled burning. [5] The ability to create fire from friction led to our ability to tolerate colder climates, fend off predators as well as cook food. This in turn led to more sophisticated cultures and further progressed technological development. A simple combustion reaction consists of the oxidation of hydrocarbons that produce carbon dioxide and water. The weak double bonds of oxygen produce an exergonic reaction in the form of thermal energy. [6] The flame is the visible portion of combustion which occurs due to the interactions of solids and gasses that release photons in the visible and infrared spectrum. [6] This one-step energy transformation is the foundational chemical reaction harnessed by a myriad of technologies from fossil fuel power plants to car engines and even a gas stove; let us next examine a typical heat engine.

Stirling Engine

The Stirling engine was conceived during the birth of the Industrial Revolution to compete with other heat engines. Robert Stirling originally patented the device in 1816, which operates by the cyclic compression and expansion of gas through external combustion. [7] Several models and configurations of the Stirling engine have since been developed utilizing the same thermodynamic principles. For the purposes of this unit, we will focus on the energy transformations associated with the alpha model. A Stirling engine consists of a heat exchanger as well as two cylinders and pistons which utilize the relationships between pressure, volume, and temperature. [7] As with all heat engines, the Stirling engine operates in four stages: cooling, compression, heating, and expansion. The thermal energy released from the external combustion (see *Combustion* subsection) transfers to a closed cylinder that contains a piston. The increase in temperature pressurizes the gas in the cylinder driving the piston. The mechanical energy generated by the piston's motion can then be harnessed to perform work. As the temperature cools, pressure is reduced causing the piston to fall back in place and the cycle to begin anew. It should be noted that the greatest amount of work is produced from the piston's driving motion during expansion. This two-step energy transformation reaches a maximum efficiency of 50% due to the constraints of thermodynamics. [8]

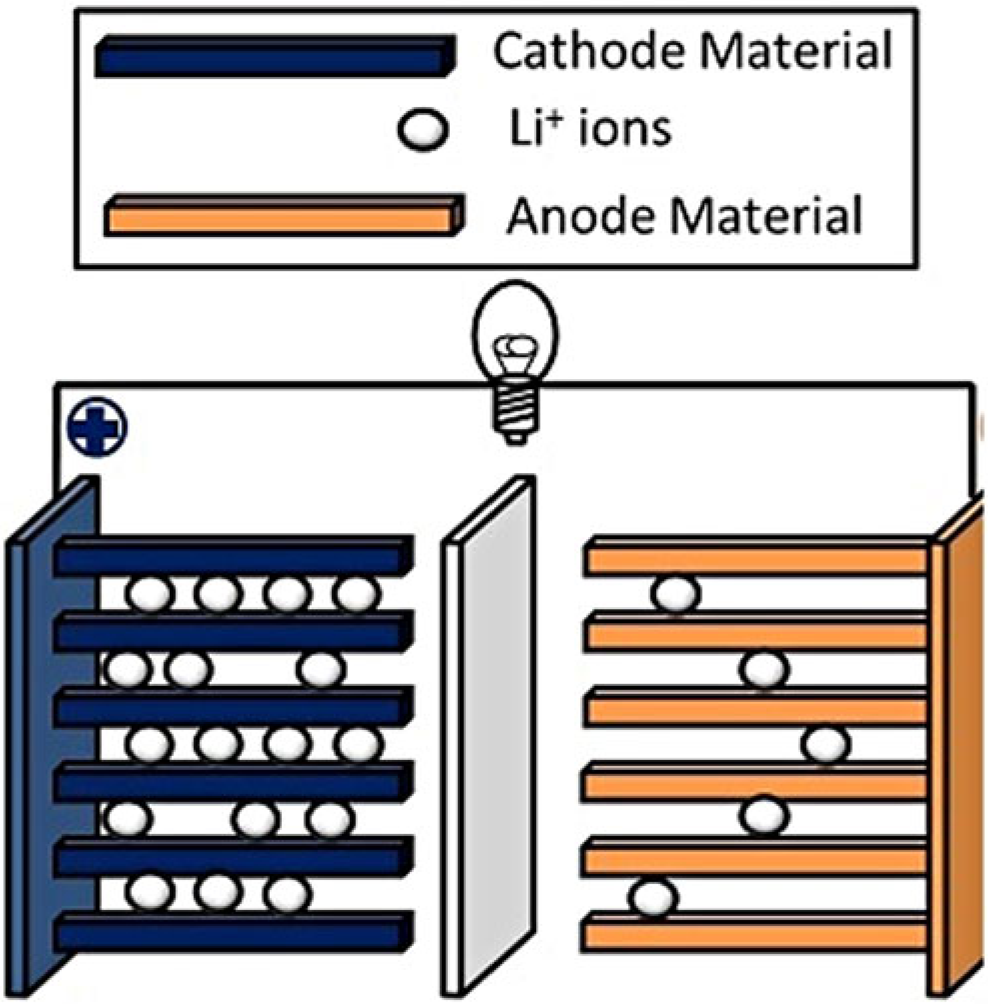
Thermal Power Plants

The various types of energy are not all economically viable, as our ability to perform work with each is dependent on the available technology. Electrical energy is by far the most commercially valuable type of energy given our 21st century demands. Electricity is generated by the static or dynamic movement of charged particles. [9] Static electricity results from a charge differential between two fixed objects whereby the energy generated is inversely proportional to the distance between both objects. Given these physical constraints, the energy from electricity often takes the form of an electrical current (i.e., alternating or direct) where sustained work can be performed. Our modern energy grid utilizes the energy transformation to generate electricity from a variety of sources (i.e., solar, chemical, mechanical). [10] Let us examine a thermal power plant where a combustion reaction supplies the necessary energy to generate 1.5 GW of electricity to the surrounding community. The main components of a thermal power plant include a boiler, turbo-generator, cooling tower, and condenser. [10] The electrical generation occurs through the mechanical rotation of the turbo-generators that produce alternating current (AC). An object that possess mechanical energy has the capacity to do work or displace an object and may come in the form of potential or kinetic energy. The turbine gains the necessary mechanical energy from highly pressurized steam. The steam produced in the boiler is at a temperature of more than 550˚C and it is led to a turbine, where its expansion pushes the blades and rotates a generator in a magnetic field to produce alternating current. [10] The vibration or rotation of water molecules provides the thermal energy that turn the angled blades of the turbo-generators. Thermal energy is a form of kinetic energy that results from movement of atoms and molecules. The combustion reaction from burning fossil fuels supplies the necessary chemical energy to vaporize the water in the boiler. The source of fuel can vary from natural gas to coal; however, the chemical energy stored within the carbon bonds is nonetheless released by a combustion reaction. This energy transformation is considered a three-step transformation with a number of pathways at each junction.

Battery

Powering portable electric devices requires far less voltage to operate, hence the development of batteries. Companies and governments are funding large battery research initiatives to enhance overall voltage yield and efficiency to meet the power demands of the 21st century. The advent of the electric car has created a market for highly efficient batteries. In addition, companies are seeking to reduce the charging time for consumers. New technologies are continually emerging; in fact, a new electric car battery recently demonstrated commercial viability by setting a distance record for a single charge of over 1,000 miles. [11] This aluminum-air battery utilizes atmospheric oxygen to fill its cathode thereby reducing the overall weight. We will examine the basic properties of batteries which ultimately are responsible for the energy that powers cellphones, alarm clocks, and smoke detectors.

All batteries utilize an oxidation reaction to generate charge, it is this potential difference which facilitates the movement of current in a closed circuit. Batteries consist of a cathode, anode, and electrolyte; the only difference is the chemical composition of the anode or cathode. The lithium-ion battery is the most widely used battery type for personal electronic devices. [12] The development of the lithium-ion battery underwent many iterations due to the volatility of the material. Lithium is a highly reactive element that ignites when exposed to water to form lithium hydroxide and hydrogen gas. A typical lithium-ion battery is comprised of a lithium-ion cell made of carbon. The electrolyte is a lithium salt in an organic solvent which is surrounded by an anode made of graphite and a cathode of layered lithium cobalt oxide. These batteries tend to be reversible which allows for multiple uses. The life span of the battery is dependent upon charge, magnitude of charge depletion and frequency of depletion. [12] Efficiency of the battery is reduced over time since there is a fixed amount of chemical energy in lithium-ion batteries and the recharging yield is less than 100%. The stored energy within the bonds of the oxidizing and reducing reagents provide the chemical energy to create a potential difference, thereby powering our electric device.



$$\mathrm{LiCoO_2} \leftrightarrows \mathrm{Li_{1-\mathit{x}}CoO_2} + x\mathrm{Li^+} + x\mathrm{e^-}$$

$$x\mathrm{Li^+} + x\mathrm{e^-} + x\mathrm{C_6} \leftrightarrows x\mathrm{LiC_6}$$

Figure 2: A schematic of a lithium-ion battery along with half reaction for the anode and cathode.

Flashlight

From the smoke detector on your ceiling to the alarm clock by your bedside, many household devices capitalize from the energy transformation(s) provided by chemical energy from batteries. We will examine a flashlight and cellphone in terms of the number of energy transformations and electrical pathways that occur to provide the various services.

A flashlight houses a battery compartment, bulb, reflector, switch, contact strips and metallic spring. The electric charge generated from the batteries is carried along the interface of the metallic spring. The switch repositions conductive contact strips that run along the length of the flashlight. The simple circuit remains open while the switch is placed in the “OFF” position, meaning that the two contact strips do not interface. When the switch is placed in the “ON” position the contact strips connect allowing the circuit to close and the electric current to flow freely. The electric current passes through the contact strip to power the bulb. Attached to the bulb is a positive electrode that completes the circuit. [13] When activated by the electrical current, the lamp begins to emit visible light. A reflector is placed at the base of the lamp to direct the emitting photons, thus producing a concentrated source of visible light. Operating a flashlight utilizes a two-step energy transformation and is a bifurcating pathway as a result of thermal and light energy being released from the bulb.

The type of bulb can dramatically affect the energy efficiency and thus the battery life of a flashlight. We will compare an incandescent light bulb to an LED and examine how each emits visible light. In an incandescent light bulb, a tungsten filament is heated by an electric current. Much of the electrical energy is converted to maintaining the thermal energy needed to cause incandescence or the emission of photons. As a result, incandescent bulbs are highly inefficient with less than 5% of the electric energy being transformed to visible light. [13] LED bulbs produce light from light-emitting diodes. Attached to an LED bulb is a microchip that produces the visible light as well as a heat sink that absorbs the thermal energy generated from activation. LEDs are 90% more efficient than typical incandescent bulbs. [13]

Cell Phone

The prolific access to cellular devices has completely revolutionized communication. Students' usage is typically confined to social media. Further examination of the electrical engineering and energy pathways may elicit greater appreciation for the technical marvel of our generation. A typical cellphone operates from the stored chemical energy in a lithium-ion battery (see *Battery* subsection) which is then transformed to electrical energy. The electric energy coupled with the intricate circuits of cellular devices provides an astonishing number of pathways for the energy to be transformed. A typical lithium-ion battery in your cellphone is 3.7 to 4.2 volts, all of which is diverted into the various functional elements that a smartphone provides (i.e., alarm, gps, wifi, music, games). [14,15] Most of the electrical energy generated by the battery is used to provide ambient light to view content on the screen. In addition, sound energy allows the operator to detect messages or incoming calls. The resistivity within the circuits of the cellphone can often generate a large amount of heat energy. Cellphones are even capable of generating mechanical energy when set to vibrate.

The display screen of a typical smartphone is made of three components: a liquid crystal display, a tiny grid of electromagnetically generating wires, and protective glass. The liquid crystal display uses an electric current and a backlight to adjust the color of each pixel on your screen. [16] When you speak into a cell phone, a microphone turns your voice into a set of electric signals. A microchip in the phone modulates radio waves to carry the electric signal over vast distances. As the radio wave passes a cell tower, the person receiving the message has the electric signals modulated to produce a sound wave. [16] The speaker in your phone contains an electromagnet and permanent magnet that vibrates a cone made of flexible material to create sound waves. The frequency of the vibrations determines the overall pitch generated from the speaker. High quality speakers often utilize various sized cones to optimize the listening experience. Among the myriad of parts inside your smartphone exists a small motor, no larger than 10 mm, that is partially off balanced. [16] A mass of improper weight distribution is attached to the motor so that when the motor rotates the irregular weight causes the phone to vibrate.

Our technological achievements of transforming energy to produce the desired outcome is truly remarkable when reflecting upon our humble beginnings of manipulating fire. However, a global infrastructure must evolve with our technological achievements if we hope to meet the energy demands.

Energy Efficiency

The United States is currently facing a mounting electric infrastructure disaster with much of it in dire need of repair or replacement. According to the American Society of Civil Engineers, the cost to replace existing infrastructure with modern technology is estimated to be up to 5 trillion dollars. [10] More than 70 percent of the U.S. electrical grid is older than 25 years with Americans experiencing more frequent and longer power outages. [10] The decrepit and derelict electrical grid will severely hinder future economic growth. In 2003, the East Coast experienced a two-day blackout that covered approximately 93,000 square miles causing 6 billion dollars to be lost. [10] Our energy challenges are multifaceted and hindered by the current political ecosystem. However, it is vital for our next generation of decision-makers to be aware of possible solutions and knowledgeable about the physical constraints of energy efficiency.

The efficiency of energy is determined by the ratio of output to initial input whether comparing light bulbs or air conditioning units. The energy differential between input to output will never achieve hundred percent efficiency due to the laws of thermodynamics. In addition, several technologies have reached limits with their ability to convert various types of energy into meaningful work. We will compare biological systems and electric devices to provide a broad context in terms of energy efficiency.

Biological systems have evolved over millennia with the changing climate and even persevered through cataclysmic extinction events. Perhaps no other biological system has had as far-reaching of an impact on the Earth as photosynthesis. Prior to the arrival of plants, the composition of Earth’s atmosphere consisted mainly of carbon dioxide and nitrogen. As plants began to dominate the planet so too did the abundance of oxygen in our atmosphere. Photosynthesis transforms solar energy into chemical energy through a series of protein and pigment complexes located in the chloroplast. The sun emits 3.846×10^{26} watts per second; however, because the sun is 9 million miles from Earth much of this is radiated off in open space. [17] Only a fraction of that energy reaches the Earth’s surface. In addition, plants can only absorb a small bandwidth of energy, in the form of visible light, due to the properties of the pigments and carotenoids. Plants only capture approximately 1.5% of the total solar energy due to limitations in wavelength absorption. [18] One might be surprised to know that photosynthesis is a highly inefficient process with 4-5% efficiency. [18] In fact, much of the solar energy is absorbed by the oceans which drive our weather systems and climate. Understanding these complex biological systems has led to research in artificial photosynthesis, with the hopes to improve solar efficiency and storage capacity. Currently, solar cells have achieved 46% efficiency with hopes of reaching up to 70% in the future.

The understanding behind the thermodynamics limitations of combustion throughout the 18th and 19th centuries dramatically led to innovations of more powerful and efficient heat engine designs. In 1824, Nicolas Leonard Sadi Carnot demonstrated the thermodynamic limitations of heat engines with the development of the Carnot Cycle and Carnot’s theorem. [19] As previously described, a heat engine operates on basis of a temperature differential that performs work. Carnot observed that thermal energy was not perfectly exchanged within the system due to entropy, resulting in engines that were unable to attain one hundred percent efficiency. Heat engine efficiency varies widely from 25% for most combustion engines to an astonishing 60% in a steam-cooled combined-cycle gas turbines. [19] The electrical power generation from this technology assembles a series of heat engines that work in tandem from the same thermal energy sources thereby maximizing heat exchange.

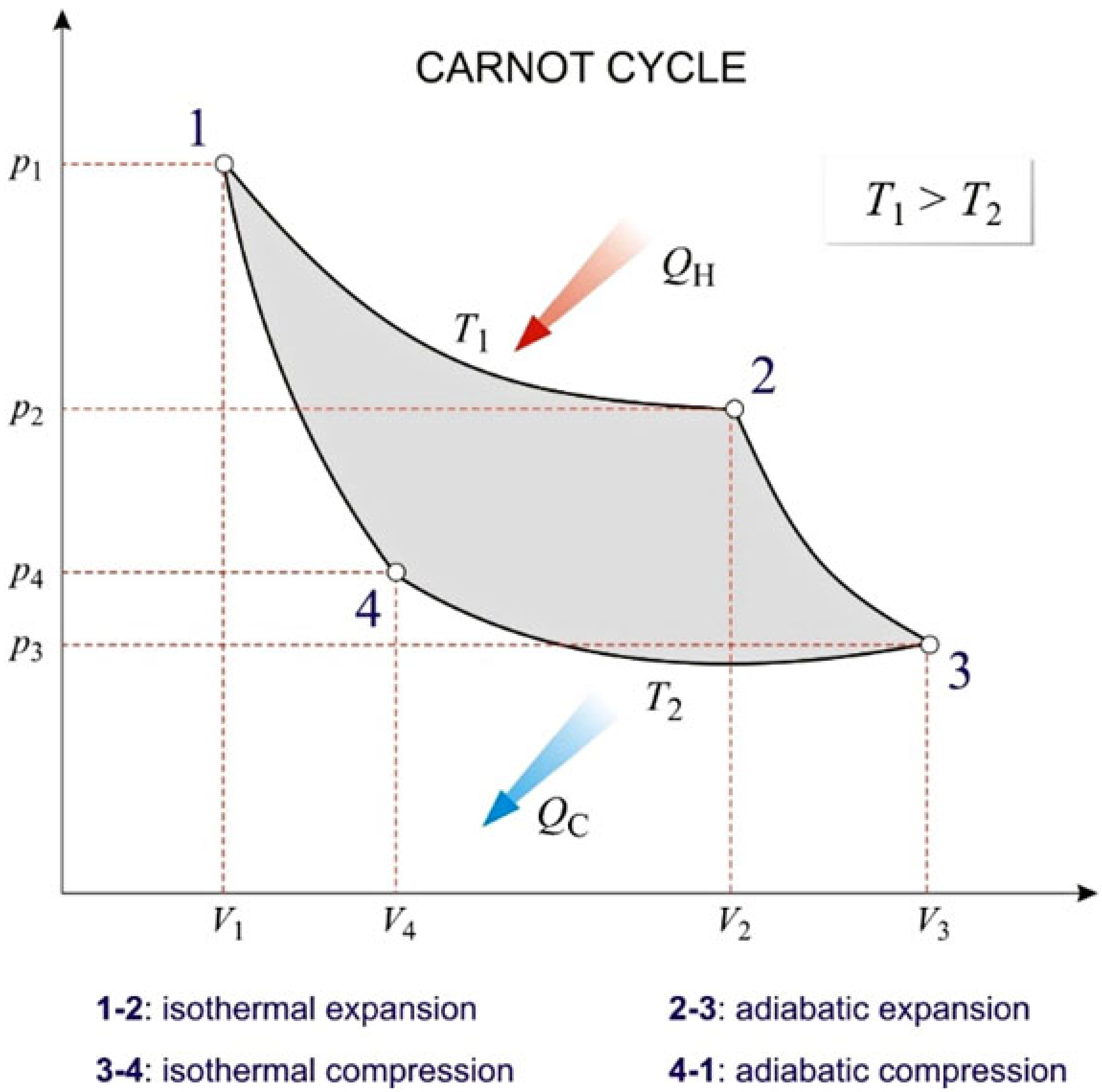


Figure 3: Depicts the Carnot Cycle and its limitations through a cycle of expansion and compression.

Technology will continue to push the physical limits of energy transformation and enhance energy efficiency as we become more environmentally conscious. Developments in solar, wind, artificial photosynthesis, and fusion all offer possible solutions to reduce our dependency on fossil fuels. However, it is imperative to be aware of the physical laws that govern our universe and gain a deeper appreciation for the existing technology that utilize these energy transformations.

Teaching Strategies

Extended Constructed Response (ECR)

Extended constructed response questions provide an opportunity for students to demonstrate the extent of mastery within a given content area while building capacity for sustained critical thinking. Students will be provided an essential question (i.e., How do the laws of thermodynamics limit the efficiency of a combustion engine? Use data to support your claims.), every two weeks, that complements an observable phenomenon or data-driven inquiry lab. The Next Generation Science Standards (NGSS) heavily emphasize students' ability to rationalize phenomena. Last year, students dramatically improved literacy skills and produced higher quality responses. To encourage a growth mindset, multiple drafts are required prior to final submission. The iterative process provides numerous opportunities for students to refine their rationale and improve the mechanics of their responses. The process must be done with fidelity and with opportunities for students to peer-review.

Station Rotation with Heterogenous Groups

Station rotation facilitates the engagements of students through several concurrent activities throughout the class period or week, depending on the model. This instructional strategy allows students multiple opportunities to refine conceptual understanding and mastery by participating in activities that target various modes of learning (e.g., kinetic, auditory, visual). Students will spend approximately 20 minutes working independently or in groups on activities. As a class, students will share findings, observations, and misconceptions that persist, once every student has rotated through each station.

The unit will concentrate heavily on deconstructing energy transformations from a myriad of observable phenomenon. Thus, it is imperative that students take detailed notes and effectively communicate their thoughts to peers. Students will be expected to take Cornell Notes, a system of notetaking the actively engages the students to ask questions, organize information, and summarize key ideas. Student groups will be compiled from pre-assessment data, attendance, and behaviors from the first 2-3 weeks of the year. At the conclusion of every advisory, student groups will be reassessed and reassembled. The number of stations may vary based on the number of students and classroom dynamics. Station rotations have been shown to be an effective strategy for students to maximize their learning and to develop skills of independent problem solving.

Inquiry Activities

As a science, physics offers opportunities for students to apply a multitude of mathematical concepts and arithmetic skills when describing physical phenomena. This unit will seek to strengthen students' content mastery of energy transformation while simultaneously refining laboratory skills and engaging in discussion. From my experience at Woodrow Wilson High School, kinesthetic activities, with a summary discussion at the end of class, have often led to the most successful lessons. This unit will utilize inquiry as an access point for student ingenuity and provide the context for students to revise their ideas about the concepts being introduced. The activity will vary in duration and rigor, requiring students to work in collaborative groups.

Activities

Energy Transformation Demonstrations – Models of Stirling Engine

Students will observe a series of phenomena to better understand the intricacies associated with energy transformations. A heavy emphasis will be placed on comparing various models of Stirling engines with regards to their energy pathways. Students will individually identify and record in their science notebooks all forms of energy observed in the initial demonstration. After three to five minutes students will collaborate in small groups to determine the energy pathway for the whole group demonstration. Students will be given ten minutes to illustrate the energy pathway starting with the chemical potential energy. Each group will present on their initial observations to prepare for the independent work. In groups of four, students will identify the types of energy present within each system (i.e., model of Stirling engine). Each group will construct an energy pathway diagram and identify forms of energy and locations of energy transformation. Individually students will be asked to explain why Stirling engines will never achieve perfect efficiency using supportive evidence from their observations as well as content from their science notebooks. This activity is designed to familiarize students with multi-step energy transformations in preparation for the culminating project at the end of the unit. This activity can be scaffolded to accommodate middle and elementary students by simplifying the observed energy transformations.

Build A Flashlight

Students will be tasked with building their own flashlight(s) out of household supplies (i.e., rubber bands, paper towel cardboard, copper wire, aluminum foil, masking tape). Prior to this activity students will have been introduced to open and closed circuits, with circuit design experience. A flashlight will be disassembled to examine the functional elements need to construct the device. Every student will sketch the electrical elements within the circuit design. As a whole group, we will identify the parts of the flashlight and briefly discuss strategies for their own designs. In groups of four, students will sketch their own designs and identify the materials needed for assembly. Students will work in groups much of the class to construct their flashlights. At the end of class, students will present their prototype flashlight as a whole group and will be asked questions about their design and choice of materials. This activity is designed to bridge content from the circuits and design to energy. In addition, it will serve as an exemplar to prepare students for the culminating project.

Measure Bulb Efficiency – Comparing Incandescent and LED Bulbs

Students will compare the differences in battery efficiency for a variety of brands (i.e., Energizer, Duracell) by estimating the energy output in lumens by utilizing their custom flashlights from the prior lesson. This activity is designed for careful observations that elicit critical thinking with regards to the chemistry present within batteries cells that utilize different oxidation/reduction reactions. Students will assess both thermal and light energy output for each battery brand produced from the light bulb. Students will record their data in their science notebook as well as the class whiteboard. Students will discuss which is more efficient based on heat generation and connect observations to thermodynamics in their conclusions. This activity is designed to elicit critical thinking about measuring energy efficiency with students identifying improvements in experimental design.

Energy Pathway of a Household Appliance or Electric Device

The summative project will task students to examine and deconstruct a household appliance. Student will likely need to conduct research to determine the intricacies of their chosen appliance and electrical device. For each household device or appliance, students will identify and describe the types of energies present, the location of energy transformation as well as develop an energy-pathway diagram. Students will be given a rubric with several checkpoints over a two-week period. Ultimately, students will present to the class about the functionality and operation of their device, the energy required for operation, and the number of energy transformations. This project will provide an opportunity for students to gain a deeper understanding and appreciation for mundane devices that are used every day (i.e., microwave, washer, phone, tv, computer).

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Teacher and Student Resources

For supplemental information that will be utilized at varying degrees throughout the unit please review the following. A deactivated link is provided along with a summary of the resource. In addition, several referenced materials are recommended for review that further supplement the content in this unit.

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. Students who require additional support should be guided to this website. (http://www.physicsclassroom.com)

Unit Reference Material

Smith, Crosbie. 1998. *The Science of Energy: a Cultural History of Energy Physics in Victorian Britain*. Chicago: University of Chicago Press.

Smith describes the historical context for the Industrial Revolution in his captivating book, "The Science of Energy". Today we take for granted our use of energy; however, if not for the works of Joule, Maxwell and Thompson our world would fundamentally operate in a different paradigm. Smith articulates the importance of each scientific discovery and the generation of industry that resulted. This book would serve as a great supplemental text to deepen student or teacher knowledge throughout this unit.

Smil, Vaclav. 2017. *Energy: a Beginners Guide*. London: Oneworld.

The abstract natural of the term energy is masterfully articulated by Vaclav Smil, who introduces the term in both past and present society. Smil not only describes the industrial context of energy but also the biological component that often gets overlooked. This resource allows readers to cover broad topics through the lens of energy. Students seeking to understand the importance of understanding energy in life and systems would be engaged through this primer text.

MacKay, David J. C. 2013. *Sustainable Energy - without the Hot Air*. Cambridge: UIT Cambridge.

The energy crisis is succinctly depicted by MacKay in "Sustainable Energy – without the Hot Air". The information is objectively presented for readers. MacKay provides scaling solutions that highlight the complex nature of the energy crisis. This book serves as a great resource for students and teachers to help understand the intricacies of various alternative energy sources.

Appendix A

Standards

NGSS Standard Integration

The unit will incorporate standards from the Next Generation Science Standards (NGSS) in Unit III. The focus will be primarily on the nature of energy and the associated thermodynamic principles.

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. (HS-PS3-1) 1

Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. (HS-PS3-1) (HS-PS3-2) 1

When two objects interacting through a field relative position, the energy stored in the field is changed. (HS-PS3-5) 1

Crosscutting Concepts

When investigating or describing a system, the boundaries and initial conditions of the system need to be defined, their inputs and outputs analyzed and described using models. (HS-PS3-4) 1

Science & Engineering Practices

Use mathematical representation of phenomena to describe explanations. (HS-PS2-2) 1