Yale National Initiative
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Curriculum Units by Fellows of the National Initiative
2007 Volume V: Renewable Energy

Stylin' Your Ride: A Student's Guide to Designing Green Vehicles

Curriculum Unit 07.05.05, published September 2007
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Introduction

This unit is designed to introduce students to various sources of energy for vehicles. It will explore the technology currently available for vehicular transportation and the technologies that are being developed for future use in vehicles. This unit is being written in 2007, which will probably be seen as a time of transition to new technologies. As a result, some of the specific technologies discussed in this unit may become obsolete; however, the unit is being written in such a way that new technological advances may be substituted in the lessons for those older technologies that become obsolete.

The unit is written for a ninth grade integrated science (sometimes called Phy/Chem) class. In our school system, that means that we cover primarily physical sciences in this class. This unit is intended to address three of the science standards we are supposed to cover: Standard 9.3 addresses the use of fossil fuels and other technologies in the generation of electricity, Standard 9.5 on the chemistry of hydrocarbon combustion, and Standard 9.9 on the environmental impact of human transportation choices.

This unit is broken into three major sections. In the first section, past and current, commonly available transportation technology options are discussed. The second section looks to the future. In this section, transportation technologies that are being developed and perfected today are discussed. This is the section that is likely to become obsolete; please feel free to substitute technologies that you feel are more appropriate to your current situation in this section. The final section of this unit is the project that the students will produce based on the information presented in the first two sections of this unit.

Activities

The students will be asked to research several types of transportation, specifically looking into several factors. The students will be asked to compile their data on a few types of transportation, and share their findings with the class. The students will use the compiled data from their own and their classmates' studies to rationally design a new transportation system. The information that follows is designed to give teachers an idea of what they can expect to come of student research. It will also give teachers an idea of where to send students looking for information. The activities are described in detail at the end of the curriculum unit.

If it ain't broke

Before I get into the nitty-gritty details of the current and future vehicular technological options, I think it would be a good idea to explain why this unit is actually necessary. Aside from the obvious concerns about needing to teach the particular curricular standards mentioned above, there is a deeper, more important, reason for teaching the curriculum unit that follows. The old saying goes "if it ain't broke, don't fix it". In the case of our current transportation network, here in America and in many other places in the world, "it" is broke. The technology that we currently use does work, but it has side effect that are untenable for long-term use. All of our most commonly used transportation technology uses the energy from the chemical combustion of hydrocarbons to move the vehicle. Even in the case of animal power, which is still common in many part of the world, hydrocarbons from foods react with oxygen in the cells to make energy. When hydrocarbons react with oxygen the inevitable products include carbon dioxide and water, both of which are greenhouse gases. In the case of animal powered transportation, methane is also sometimes produced. Methane is also a greenhouse gas. As a result, the technology must change, and sooner is better than later.

All of the previous information is discussed in much more detail in the following sections. However, it is the necessary basis for the discussion of the greenhouse effect that follows. Al Gore's book and movie both entitled "An Inconvenient Truth" give a good explanation of what the greenhouse effect is and why it is important. Most Earth science textbooks and many biology textbooks also give an explanation of the greenhouse effect. However, I will also give a basic explanation of it here.

When energy is released from the sun, it travels through space in the form of electromagnetic radiation. Eight minutes after leaving the sun, the electromagnetic radiation reaches the Earth. Some of the high energy electromagnetic radiation is absorbed in the upper atmosphere by molecules like ozone. The slightly lower energy electromagnetic radiation in the visible light part of the electromagnetic spectrum mostly passes through the atmosphere and reaches the surface of the Earth. Much of the electromagnetic radiation that passes through the atmosphere is absorbed by the soil, water and vegetation on the surface of the Earth. Some of the radiation is reflected back into space by clouds, snow, glaciers, and other shiny material. And, some of the electromagnetic radiation is reradiated at a slightly lower energy wavelength in the infrared portion of the electromagnetic spectrum. Some of this reradiated portion of the sunlight is trapped by various gasses in our atmosphere called greenhouse gasses and is reflected back to the surface of the Earth. This reflected radiation is also absorbed by the soil, water and vegetation on the surface of the Earth, causing the Earth to warm. This naturally occurring feature of the Earth's atmosphere is known as the greenhouse effect and allows our planet to be warm enough to support life as we know it. However, the problem comes when there is too large a concentration of greenhouse gasses in the atmosphere. Too much greenhouse gas causes the atmosphere to trap too much energy, causing the Earth to retain too much heat. If the Earth gets too warm, life as we know it ceases to exist.

There are many, many ways that the worst consequences of the above mentioned catastrophe may be avoided. Al Gore offers several suggestions at the end of his book and his movie about what average citizens can do, and I recommend reading his book, watching his movie, or visiting his website for these suggestions.

However, the issue I focus on in this curriculum unit is the possibility of reducing our dependence on the combustion of hydrocarbons to fuel our transportation.

Old school Technology

All of the energy currently available on the Earth ultimately derives from two sources: the thermonuclear reactions in the sun and the thermonuclear mechanisms found on and in the Earth. The energy used in most transportation is derived ultimately from the sun. The only form of transportation that does not ultimately derive from the sun is the use of nuclear power, derived from minerals found on Earth, to power nuclear submarines and to provide electricity for a few electric vehicles. In each of the descriptions of the technologies which follow, the consequences of the use of this energy will be described.

Humans have used and currently use many different forms of transportation. All of these methods of transportation have advantages and disadvantages. This unit will explore the advantages and disadvantages of these transportation options from the perspective of human impact on the environment, primarily the human impact on global warming.

Non-Combustion Technology

There are three major sources of non-combustion transportation energy that have been or are currently in common use. The first of these energy sources is animal power. This category includes draft animals, beasts of burden, and human powered vehicles. The next energy source is wind power. In the transportation sector, wind power has been used primarily over water. However, wind turbines are also a promising area for new electricity generation and have been used and are still used to grind grain and pump water. The third source of non-combustion energy is nuclear energy. Nuclear energy is presently used for transportation only in nuclear submarines and a few electric vehicles.

Animal Power

Animal power is the original form of mass transportation. The earliest evidence of animals domesticated for transportation dates from about 6000 BC. Various animals have been used for transportation including horses and other equids, oxen and other bovids, camels and other camelids, elephants, and humans. Horses have been domesticated for at least 4000 years. There is some evidence that wild horses were tamed and used for riding during the millennium before that [1]. Because of their anatomical structures, horses are more suitable for riding than some of the other equids like donkeys. As a result, in places where horses were less available, donkeys and other equids were used to draw vehicles. Evidence for two and four wheeled vehicles has been found from as early as the 4 th millennium BC in the Middle East. Similarly, evidence of oxen being used to draw four wheeled carts is found from the 3 rd and 4 th millennium BC in the steppes of southern Russia [2]. Camelids were domesticated in South America between 6,000 and 7,000 years ago and were used as food and fiber sources and as well as beasts of burden [3]. Except for the dogs mentioned below, there were no draft animals used in pre-Columbian South America or North America. Dromedary camels (one hump) appear to have been domesticated 3000 to 4000 years ago in southern Arabia. Evidence for Bactrian camel (two humps) domestication has been found in Turkmenistan and eastern Iran from the 3 rd millennium BCE [4]. Dogs have been used to pull sleds in some cultures of the arctic region for about 1000 years [5]. Finally, elephants have been domesticated in India since about 6000 BCE [6].

Humans have, of course, transported ourselves and our belongings since we have had belongings. In a few remote places, humans are still responsible for most of the transportation. In some major cities, particularly in warm climates or warm weather, human energy is still a common form of transportation. Humans get around by walking, bicycling, rowing boats, and by rickshaw in many places around the world today.

Pros and Cons of Animal Powered transportation

There are certainly advantages to using animal transportation, and for thousands of years it was a major contributor to world transportation. However, there are some very good reasons that it is less common today than it was. Animals require a large amount of daily care and maintenance. Machines generally do not require daily care and feeding. Animals generally produce less carbon dioxide than other methods of transportation; however, many animals, particularly ruminants like bovids, produce methane, which traps heat in the atmosphere more effectively than does carbon dioxide. Finally, animal power is also much slower than most vehicles. However, in some parts of the world, particularly in areas of extreme climate or terrain, animals are still the chief method of transportation because they are more mobile than wheeled vehicles.

Human transportation is certainly a good option for movement in a small area with little baggage. Moving one's self is good exercise and is generally good for one's health. Finally, walking also eliminates the need to find parking and the problems inherent in paving over section of the surface of the Earth. However, human transportation does take more time than some of the other options listed below, and it does require the expenditure of more calories than most of the options listed below. Furthermore, it is difficult to transport large, heavy or bulky items using human-powered transportation systems even with tools such as wheel barrows, hand carts, and rickshaws. Finally, human transportation over long distances, while possible, is generally not feasible in a timely manner. Although there are some cultures where human-powered transportation is still the common type of transportation, they are rare.

Wind Power

Wind-powered boats are an ancient form of transportation. There is evidence that early cultures in the Middle East, the Mediterranean, Africa, Southeast Asian, and China developed boats that used the wind to propel them. I have not been able to find any evidence that wind-powered boats were used in the Americas before European contact.

The essence of wind power is that a vehicle is propelled by moving air. There are two types of sail that are attached to the boat to capture the moving air. Square or rectangular sails are attached to a mast and are most useful when the wind is moving the air in more or less the same direction as the vehicle. Triangular sails are somewhat more versatile as they may be used to harness the power of the wind when the wind is moving the air more perpendicularly to the direction of the motion of the vehicle.

Wind power is generally associated with boats in open water. However, in the 1800s an iceboat was developed which used wind to power a vehicle across ice. The ice boats look like a platform on two or three blades with a sail. The boats appear to have been used primarily for entertainment in the form of racing during the winter. They were popular on New York State's Hudson River.

Wind power is not generally use much for transportation now, but I have included it in this curriculum unit for two reasons. First, wind-powered turbines are likely to become a significant source of energy in the future, and the inclusion of wind-powered vehicles provides an opportunity to discuss wind power in many contexts. Second, New Haven, where my school is located, is built around a harbor, so wind-powered transportation across the harbor and our several rivers, or boats more generally, may be an option my students will wish to consider when they work on their projects at the end of this unit.

Pros and Cons of Wind Power

Wind power is most useful when the wind is blowing in a convenient direction. It causes no pollution, except in the manufacture of the wind harnessing technology. It has no detrimental environmental effects when used to propel vehicles.

There are a few drawbacks to wind power, though. When they are improperly sited, wind powered turbines have been known to cause bird deaths. This hazard can be avoided or minimized by careful siting to avoid common bird flight paths. Finally, the most obvious drawback to wind powered vehicles is that wind power for vehicles is useful only when the wind is blowing in a useful direction. Furthermore, the speed of travel is limited by the amount of energy that may be harnessed from the available wind. However, for several centuries, much of the international commerce, travel, and warfare of the world was carried out using wind-powered vehicles.

Nuclear Power

Nuclear energy comes in two forms, fission and fusion. Fission is the process of breaking apart atomic nuclei. Fusion is the process of putting together atomic nuclei. Both processes release a very large amount of energy. Both forms of nuclear energy are used to make weapons, but only fission is currently able to be harnessed to do useful, nondestructive, work.

Fission is used in nuclear powered submarine reactors to provide propulsion in the oxygen poor undersea environment. It has the advantage of being a technology that provides energy for a long period of time without the need to refuel. Nuclear submarine engines are reasonably quiet, and they do not require oxygen as Diesel powered submarines do.

Fusion actually provides most of the energy required for life on Earth. The energy provided by the sun is generated by the fusion of hydrogen into helium in the core of the sun.

Pros and Cons of Nuclear Power

Nuclear powered vehicles have the same problems as nuclear powered electricity. The first problem is that nuclear fuel for fission is a large, but ultimately finite, resource. Second, fusion, while capable of providing vast amounts of energy has not yet been harnessed in a way that did not destroy its containment device. The process of fusion provides so much energy that it can not be contained, so it is currently useful only in the form of solar energy, where the source is very far away, and in the form of thermonuclear weapons. Finally, the most commonly cited problem with nuclear power is the waste disposal from spent nuclear fuel. The problem with spent nuclear fuel is that it is still radioactive. The two major types of nuclear reactors produce two different types of waste. In the US, reactors produce large quantities of moderately radioactive waste. In other countries, many reactors produce smaller amounts of very radioactive waste. In either case, nuclear reactors produce radioactive waste. Radioactive waste is a problem because it is toxic to human health and remains toxic for thousands of years. It eventually degrades its containment system and can be a security threat. Today there is concern that radioactive substances, waste or fuel, may be used to make dirty bombs, explosive devices used to scatter radioactive substances over a large area. Depending on the radioactivity of the material used these bombs potentially range from a nuisance to a very deadly hazard.

Combustion Engines

The combustion engine has been in use in automobiles for a little over 100 years. The combustion engine has been used by railroads for a bit over 150 years. However, the first combustion engines were used not for transportation, but rather for driving industrial processes. In late 1600s and early 1700s, several Europeans developed early versions of steam engines. Several ancient cultures also used steam driven devices as toys and religious paraphernalia [7].

All combustion engines are based on technology which captures energy from combustion, the chemical process of combining hydrocarbons with oxygen, and converts the energy that formerly resided in the carbon-hydrogen bonds of the fuel into the mechanical energy which moves a vehicle or other machinery. The products of the combustion reaction include water vapor and carbon dioxide, both of which are greenhouse gases.

External Combustion

External combustion engines have a combustion chamber that is outside the engine. The most common use for this type of engine is the locomotive steam engine, which is quite a bit less common than it used to be. However, the Sterling engine is also traditionally considered an external combustion engine. It is now making something of a comeback using solar energy instead of combustion. It will be discussed in the new technology section later in the unit.

Steam power

Steam power is one of the oldest forms of power for mechanized vehicular transportation. In a steam locomotive engine, combustion heats a second substance, like water, which then drives a piston in a cylinder. The motion of the piston is transferred to a drive rod, which drives the wheels [8]. Traditionally, coal is the source of the fuel for the external combustion. So, a coal car was attached immediately behind the locomotive. However, in order to make the engine work, water was also required.

Clearly, given the scarcity of steam locomotives today, this technology had some serious drawbacks. Some of the more evident include the fact that a human being needed to constantly tend the open flame in the firebox. The fireman had to feed the fire, an open flame in a box on a moving, jostling platform, with sufficient coal to create the steam that the engineer needed to make the locomotive perform. This was a dirty and dangerous job. The engine had no filters on the exhaust from the fire box, so the engines were notoriously sooty, and, while it may not have been recognized at the time, coal combustion fumes contain many toxins beyond particulates including oxides of nitrogen and sulfur. Additionally, the engine required a constant supply of water, which had to be replenished frequently. In summary, the steam locomotive burned coal without filters, creating carbon dioxide, to heat water, creating water vapor, and was generally a dirty, dangerous method of transportation.

Despite its obvious drawbacks, the steam locomotive persisted for about 50 years because it served an essential transportation function in a world where the alternatives were all animal powered. The steam locomotive allowed large numbers of people and their possessions to be transported large distances in a relatively short amount of time.

Some modern steam engines use piston technology as the locomotive does, but many steam engines use turbines instead. In a turbine engine, the rotational energy of the turbine shaft is used by whatever the turbine is designed to power. Modern steam engines, generally of the turbine variety, are used in nuclear and some other power plants to generate electricity.

Although the steam locomotive is a fairly obsolete technology, I think it is important to include it in the mix of options for the students to use in the design of their vehicles at the end of this unit because it will allow the students to consider some options that may not be ideal. Furthermore, most nuclear reactors still use steam turbines to generate power, and this topic will allow the class to discuss other uses of turbines including hydroelectric power generation and wind turbines.

Internal Combustion

An internal combustion engine is one in which the combustion of fuel, generally a fossil fuel today, takes place inside the engine. The combustion of the fuel causes a piston to move which then drives various other mechanisms and ultimately leads to movement of the entire vehicle.

Diesel

Diesel engines operate slightly differently than engines designed for unleaded fuel, ethanol or mixed ethanol/petroleum fuels. Diesel engines generally operate at a higher efficiency than other internal combustion engines, which means they produce less CO_2 per mile traveled, but there are disadvantages to Diesel, which include pollutants inherent in the fuel itself.

The Diesel engine operates by capturing the energy from exploding Diesel fuel. A small amount of Diesel fuel is allowed into the combustion chamber of a cylinder which contains compressed air and explodes. The explosion pushes the piston towards the other end of the cylinder. The motion of the piston via the connecting rod drives the crank shaft which ultimately makes the vehicle move. Please note that the Diesel engine does not have spark plugs. Once again, "How Stuff Works" comes to the rescue with a very fine explanation, moving diagrams, and answers to difficult questions [9].

Diesel fuel derived from petroleum contains contaminants inherent in the fuel such as sulfur and nitrogen. When the fuel is combusted, these pollutants are combusted as well. Diesel fuel contains anti-knocking agents. These chemicals are included in the fuel mix to ensure an even explosion in the cylinder. Traditionally, lead was used for this purpose in Diesel. This caused large amounts of lead contamination to accumulate on the sides of roads and in places downwind of highways. Children playing in these areas developed lead poisoning because they inhaled and ingested the lead contaminated exhaust particulates. The particulates themselves, even without the addition of lead, are harmful as well. Diesel engines are somewhat more susceptible to particulate emissions than gasoline engines because small amounts of oil are more likely to be burned with the fuel than in gasoline engines. The particulates tend to be bits of ash, and droplets of uncombusted hydrocarbons from the fuel and from oil.

When particulates are inhaled by the human body several things can happen. Bigger particulates are trapped in mucous lining the airways. The mucous is them pushed up and out of the airways by tiny hairs lining the air passages called cilia. The particulate laden mucous is then passed through the digestive tract or is coughed up and out of the body. Smaller particles continue passed the mucous lining and lodge in the lower portions of the lungs. There, the particles will either stay and block oxygen-carbon dioxide exchange, pass through the gas-blood barrier and enter the blood stream, or be coughed out. Particles that remain in the lungs can interact with the cells of the lungs and cause damage including emphysema and cancer. Particles that pass through into the blood stream either through the digestive tract or directly from the lungs can also cause long term damage like brain damage and cancer. Incidentally, particulates from other sources like cigarette smoke and wood smoke can also cause similar damage for similar reasons.

Unleaded

Unleaded gasoline engines contain pistons and cylinders like Diesel engines, but the pistons are driven a bit differently. In a gasoline engine, air is mixed with the fuel prior to entering the combustion chamber. The air and fuel mixture is compressed, but not as much as it is in a Diesel engine, and is ignited by a spark plug. Both John Muir's book and "How stuff works" contain detailed explanations of this process and its variables [10, 7]. John Muir's book came highly recommended to me and, although it focuses on one specific brand of car, the illustrations and text are more generally applicable.

Unleaded gasoline combustion has the typical combustion problems in that it produces carbon dioxide and water vapor. The gas is mixed with the oxidant so that it burns more completely, creating less carbon monoxide. However, the engine is somewhat less efficient than the Diesel engine because of the lower compression ratio in the cylinder. This means that, although the gasoline engine burns more cleanly than the Diesel engine, the Diesel has the potential to use less fuel, producing less carbon dioxide.

The oxygenate used to make gasoline combust more completely has its own risks, though. For many years, methyl tertiary butyl ether (MTBE) was used as the oxygenate in gasoline. However, it was found leaking out of underground gasoline storage tanks, contaminating local drinking water supplies. As a result in many places, it has been replaced recently by ethanol. The ethanol replacement is distilled from crude oil as is the gasoline. However, as mentioned in the next section, ethanol can be made from biological organisms.

Ethanol

Ethanol has been in use in Brazil since 1975 [11]. It is used to supplement or replace gasoline, depending on the type of engine in the car. Most car engines can handle some ethanol; here in Connecticut, up to 10% ethanol has been added to our gasoline in place of MTBE. In Brazil, ethanol has been produced on a large scale from sugar cane for use in place of gasoline since the oil embargo in the 1970s. However, there are modifications that need to be made to an engine to allow for the combustion of large quantities of ethanol. Flex fuel engines are designed to accommodate variable percentages of unleaded gasoline and ethanol.

Flex fuel engines are designed to run on gasoline or ethanol or a mixture of the two. As stated above, fuel and air are injected into the cylinder of a gasoline engine; the mixture is compressed and ignited by the spark plug, causing the piston to move, eventually moving the vehicle. When ethanol is used in place of most of the gasoline, like in E85 (85% ethanol, 15% gasoline) mixes, a higher amount of compression is needed in the cylinder to make the engine run properly. There are several advantages to using high percentage ethanol mixes which will be discussed later in the funky fuels section of this unit.

Computer Controls

Computers are used in cars in many ways today. In addition to the evidently visible places like the CD player or GPS, computers are also used under the hood. Computers are used to regulate the amount of fuel entering the combustion chamber in the cylinders of an engine. The precise control available through computers allows fuel to be mixed with air at different ratios for different purposes. This allows the engine to burn fuel more efficiently because the right amount of fuel is combusted for the specific needs of the moment rather than an averaged amount which might be overly rich (too much fuel) and, therefore, wasteful.

Jet Propulsion

When air is heated, like all gases, the pressure increases. In a jet engine, fuel is injected into a large tube-shaped engine to heat air as it passes through the engine. The heat causes the air pressure inside the engine to increase. The higher pressure air moves towards the area of lower pressure outside the back end of the engine. When the hot air exits the engine, it causes the engine, and the attached plane, to move in the opposite, forward, direction. The exiting air creates a vacuum which sucks in new air to be heated by the injected fuel, and the cycle repeats. To ensure that the heated air leaves through the back of the engine rather than the front, the engine must be moving forward when the air is first heated so that the air is already moving in the correct direction when the air is heated. This means that jets must have at least two sets of engines: one to get the plane moving in the right direction and the jet engine.

A jet ski works in a way that is similar to that of a jet airplane. The jet ski pushes water out of its engine instead of air. The jet ski pumps water in to a tube and pushes it out of the back end of the vehicle. Newton's third law of motion demands that if water is pushed out of the tube, the tube must be pushed forward. Since the tube is attached to the jet ski, the jet ski is pushed forward, too. Incidentally, a number of sea creatures, including squid and octopus, propel themselves through the water this way.

Although a jet airplane is not a practical solution to transportation within a city like New Haven, it is important again to include jet propulsion in the mix of possible technologies from which the students will be able to draw inspiration for their project at the end of the unit.

Catalytic converters

Catalytic converters are one of the few technological advances which decrease the pollution output of automobiles without increasing the efficiency of their engines. A catalyst is a substance that lowers the energy required for a reaction to move forward. However, the catalyst is not used up in the reaction. Some catalysts are used and recreated and others like biological enzymes offer a specific reaction site that improves the efficiency of a reaction. The catalytic converter uses a platinum catalyst or another metal catalyst coating on a gas exchanger to convert toxins in the exhaust like carbon monoxide and oxides of nitrogen to less toxic substances.

Catalytic converters have few downsides, however. They are expensive to produce because the metal catalyst tend to be made from very pure and fairly rare metals.

New School Technology

There are several technological advances being explored by car manufacturers and other innovators today. They fall into several broad categories. The first explored in this unit is the area of new or alternative fuels. In the funky fuels section, design options that use the basic ideas of an internal combustion engine burning innovative fuels are discussed. The next broad category includes the new engines. In the funky engines, section innovative ways of capturing and using energy are explored. The last section includes some new ideas about making the technologies that we currently use, work more efficiently. The funky materials and designs section introduces ideas about weight reduction, size reduction, and drag reduction, all of which reduce the amount of fuel needed to move a vehicle.

Funky Fuels

Biofuel

Biofuel is fuel that is derived from recently dead organisms rather than from the long dead organisms that make up crude oil. It is a broad category that includes biodiesel, ethanol, and methane, and other similarly combustible substances. All of these substances are combusted in internal combustion engines similar to those available today. However, they reduce the user's reliance on crude oil and natural gas. Like most of the options mentioned in this unit, there are benefits and problems with these options. The benefits and drawbacks of biofuels will be discussed in this section of the unit.

Biodiesel

Biodiesel is a fuel consisting of long chains of hydrocarbons. The hydrocarbon chain length is typically longer than those found in crude oil derived Diesel fuel. Biodiesel is made from biological lipids. Lipids are long chains of hydrocarbons that are connected together in groups of three by a short glycerin molecule. The entire lipid molecule looks like the letter "E" with very long horizontal lines. I will explain the concept of a lipid to my class before this section. These lipids can be plant oils or animal fats. The lipids are combined with methanol or ethanol and sodium hydroxide. The methanol or ethanol reacts with the hydroxides to form methoxide or ethoxide. The oxides combine with the long hydrocarbon chains in place of the glycerin. This results in three separate hydrocarbons in place of the one lipid and a glycerin molecule. The mixture of hydrocarbon chains and glycerin is separated and the hydrocarbon chain solution, now referred to as biodiesel, is washed with water to remove excess methanol. The US Department of Energy, office of energy efficiency and renewable energy website has some good, mostly unbiased, information on how biodiesel is made, sold, and used [12]. If you are interested in making you own biodiesel, there are many, many resources available to help through the process. However, if you are making biodiesel with students, please be sure to use good ventilation.

Biodiesel is most commonly used in combination with crude oil Diesel. It tends to be a bit corrosive of rubber parts in the engine and fuel lines. However, it has several advantages. First, it can be made near any source of biological lipids. This means that it does not have to be transported long distances or half way around the world. Biodiesel is made primarily from material that would otherwise be wasted, so it reduces the amount of waste that goes into landfills. Biodiesel is made from carbon sources that have not been sequestered for hundreds of millions of years, so it does not add extra carbon to the atmosphere when it is combusted. Biodiesel does not contain sulfur and other impurities that are found in crude oil Diesel, so when it is combusted, it produces less harmful emissions than crude oil Diesel.

Biodiesel is becoming a more commonly accepted fuel as the prices of crude oil rise. However, it has limited applicability on a large scale at the present time because there is a limited amount of biological lipid that is available for conversion to biodiesel.

Bioethanol

Most of the ethanol used in fuel today is distilled from petroleum. However, humans have been fermenting ethanol from biological sources for thousands of year. Beer, wine, and distilled spirits all contain ethanol. The process of making bioethanol for cars can be very similar to that of making ethanol for human consumption.

There are two methods of making ethanol from biological sources. In the first, sugar or starch is fermented by yeast or other equally adept critters. The critters are strained out of the fermented liquid and reused. 95% pure ethanol is made from the fermented liquid by distillation, a process which separates most of the water from the ethanol. The ethanol is then typically mixed with methanol to make it unfit for human consumption and it is ready to use. The second method for making ethanol from biological sources is a bit more complicated because the ethanol is produced from the cellulose in the plants. Cellulose is the part of the plant that gives it most of its firm structure. If you buy a box of starch, you get the soft starch inside and the firm wood pulp fibers of the box. The wood pulp fibers that make the box are primarily cellulose. Yeasts do not eat cellulose, however, so a different solution from that of starch fermentation is required. In the same way that starch is more easily incorporated into water than the cardboard box the starch came in, starch is more easily broken down than cellulose. To break down the cellulose requires the bacteria from the gut of cellulose digesting animals like termites and ruminants. However, even these bacteria are not very good at digesting cellulose. A chemical process can be used to break the cellulose into glucose, a simple sugar, but the chemical process is not very precise and creates quite a bit of waste. As a result, there are no efficient technologies currently available for the manufacture of ethanol from cellulose.

As stated earlier, the Brazilians have been making bioethanol fuel successfully from sugar cane since 1975. Unfortunately, our government has placed very large tariffs on Brazilian sugar to protect our own sugar producers. This means that the most cost effective way to make bioethanol in the US is to make it from corn, which, while protecting the corn and sugar industries, is energetically inefficient. Corn growth requires large inputs of petroleum derived chemical fertilizers and pesticides and produces very little fermentable material. This means that while ethanol can be produced from corn, our current technology does not allow us to produce it in a way that provides more energy output than input. Furthermore, corn, or maize, is a dietary staple of much of the world. If large portions of the US corn harvest, which currently feeds much of the world, are directed towards the production of bioethanol, the price of food is likely to rise.

Hydrogen

Hydrogen as a fuel has been promoted by our current president, but there are several problems to be solved before it becomes a viable commercial fuel. At the moment, it looks like hydrogen is most likely to be used in fuel cells. Fuel cells are described in the next section. The two biggest sources of hydrogen in the world are water and hydrocarbons. In both cases, hydrogen can be extracted, but it requires energy to do so. This is the first problem. The second problem is that once the hydrogen has been extracted, it needs to be stored or used. Hydrogen on its own is a gas at temperatures most commonly found on Earth. This makes storage and transportation bulky and complicated.

Methane is one possible source of hydrogen for fuel cells and is readily manufactured by biological organisms. However, it is four times more potent a greenhouse gas than carbon dioxide, is volatile and difficult to transport, and still produces carbon dioxide when used for energy. Most other, slightly larger hydrocarbons have also been suggested as sources of hydrogen. While many of the slightly larger hydrocarbons do not have the problems of gas storage associated with them, they all have the same fundamental problem. The hydrogen is bound to carbon. When the hydrogen is disconnected from the carbon in the presence of oxygen, the carbon forms carbon dioxide, which is the present problem with hydrocarbons as a fuel source.

Water is also a source of hydrogen. In the long term, I suspect that water may be the likely source of hydrogen used in fuel cells because water also contains the oxygen needed to run fuel cells. Water does not have the issue of potential carbon dioxide formation, and water makes up almost three quarters of the Earth's surface. However, to obtain hydrogen from water, energy input is still required. Electrolysis has been used to separate hydrogen and oxygen in water for years, and only requires the input of electricity. Unfortunately, if the purpose of the hydrogen is to generate electricity, this system does not work too well. However, if the electricity is generated by solar or wind power, then hydrogen and oxygen separation becomes a form of stored energy. I suspect this may be how hydrogen and fuel cells will eventually be used. Alternatively, this section of the curriculum unit may become laughably obsolete.

For more information on hydrogen, its potential and its problems, I suggest The Hydrogen Economy. Having come across it shortly before finishing my second draft, I haven't read much of it yet, but it looks very promising.

Funky Engines

Fuel cells

The idea for a fuel cell was conceived in 1894 by W. Ostwald, so strictly speaking it isn't new technology. In fact, four types of fuel cells are discussed in The way things work, which was published in 1967 [13]. However, the fuel cells that are being developed and used today use new materials to work more efficiently at room temperature and atmospheric pressure.

Fuel cells are a popular option, particularly here in Connecticut where much of this new technology is being developed. A fuel cell produces electricity to power an electrical motor. The fuel cells being developed today combine hydrogen and oxygen across a semi-permeable membrane producing a flow of water and a flow of electrons. The electrons are connected into a circuit which does work, like moving a vehicle or running computers in space.

The biggest hurdles facing fuel cells today appear to be technological. The membrane which separates the hydrogen from the oxygen is fragile and expensive. This means that it has to be replaces frequently and is very expensive to do so. If an appropriate barrier can be made inexpensively and/or durably then fuel cells are likely to be come more common. The other major issue, as mentioned above, is the source of hydrogen for the fuel cell, but again, this is a surmountable obstacle with appropriate technology.

Electric/Plug in

Electric motors have been available for a long time. The railroads in the Northeastern United States have run on electricity for years. Many of the mass transit systems in major cities also run on electricity. The reason this type of engine is listed under new technologies is that automobile engines are now being developed that run on batteries rather than on the active power lines of the past. Strictly speaking, like the fuel cell, the electric car is not actually new technology. In 1996, GM commercially produced and sold the EV1, a fully electric car.

There are two major hurdles with this technology, transportation and storage. Both involve the nature of electricity. Humans have actively studied electricity for a few hundred years. Benjamin Franklin is famous for his key on a kite experiment, and various others including Volta, Ohm, Tessla, and Faraday did quite a bit of research in the 1700's and the 1800's. Edison, of course, is largely responsible for our current wide spread electricity use today. However, with the possible exception of nuclear energy, humans have been exploiting most other forms of energy in one form or another since before recorded history. So, in the grand scheme, electricity is fairly new. As a result, we have yet to develop technology to which is able to store and transport electricity without a fairly large amount of waste.

Most of the potential solutions to the storage and transportation issues rely on technology that is not yet fully functional. One potential solution to the problem of electricity storage is to use a fuel cell to generate the electricity from hydrogen and oxygen on the vehicle. The problems with this solution have been described above, though, in the fuel cells section of this unit. Another solution is to use something like solar power to generate electricity, particularly on large vehicles like trains, trucks or buses, which would have a fairly large surface area that could be used to collect sunlight. The problems associated with solar collection are detailed in the next section, however. Finally, batteries can be used, and currently are being used, but they have their own sets of issues. The currently available rechargeable car batteries have a life expectance that is significantly less than that of the rest of the vehicle. The batteries are very expensive and tend to contain toxic materials that are difficult to recycle. As a result, the electric and plug-in vehicle which does not run on railroad tracks will likely be available soon, but there are some technological hurdles to overcome before it is a reasonable alternative to the combustion engine. For more information on why we do not have electric cars on the road today, I recommend the documentary "Who killed the electric car?", put out by Sony Pictures. The documentary has some bias to it, but I have yet to find a source of response from the car companies involved.

Solar

Solar powered cars are a popular design project at universities around the country. However, university students have yet to develop a practical and efficient way to harness the energy of the sun. Some of the issues with this technology are similar to those of electrical motors; however, solar capture technology also has a long way to go before it becomes practical for use, particularly at high latitudes.

Solar energy can be harnessed in a number of ways. Plants harness solar energy by splitting water and sequestering carbon. Unless you are solely eating from a food chain that relies on deep sea vent creatures, you and I are sustained by this method of harnessing solar power, too. Solar energy can also be harnessed by using it to create thermal differences. Passive solar heating in a house works this way. Solar energy can also be harnessed through chemical means, and for transportation this is more to the point, at least right now it is. Solar powered cars are being developed that run electrical engines powered by photovoltaic cells.

Photovoltaic cells work by generating electrical current from electron donating chemicals. When light hits certain types of chemicals an electron will be bumped to a higher orbital. If the electron is tempted out of its higher orbital, it may be removed from its original atom completely. If it is not tempted away, the electron will eventually return to a lower orbital releasing energy as it moves. However, if the electron is moved away from its original atom, it can be combined with many others to form electrical current. This is essentially how photovoltaic cells work. Light hits the cell and electrons are removed from their original atoms. The electrons form a current and go off and do work. The circuit brings them back to the photovoltaic and they find a happy home back in lower orbital of an atom where they can start the process all over again.

Theoretically, this is great. In actual fact, we are not very good at convincing electrons to leave their atoms and move around the circuit. Plants are not all that good at it either, but they make up for it by using lots of light receptors. There are several problems with solar power. The biggest problem with using solar energy right now is that photovoltaic cells are not very efficient. They are almost cost effective in places close to the equator that have little cloud cover for businesses that only need power during the day. In fact, quite a few businesses have installed photovoltaic cells on the roofs of large warehouse type buildings, use power they generate during the day, feeding excess electricity into the power grid and feeding off the grid at night. However, this only works because they have a large amount of roof to cover and can retrieve energy from other sources at night. Most of the world does not live near the equator, though, and, here in New England, we have lots of cloud cover. As a result, inefficient photovoltaic cells do not make much economic sense here. Another major problem with photovoltaic cells, particularly for transportation, is that they only generate electricity when they are receiving solar energy. This means that they do not generate electricity at night, while going through tunnels, on rainy days, north of the artic circle in winter, etc. In order for a solar powered car to work at night, the car must be able to store excess energy. This brings us back to the aforementioned battery problem again. In short, solar powered vehicles are not available yet because we do not have an efficient way to harness solar energy and, even if we did, we do not have an efficient way to store it for darkness or other adverse times.

Hybrid engines

Hybrid engines are engines that use more than one type of energy to propel a vehicle. Most of the hybrid engines on the market today use gasoline and electric motors to move the vehicle. However, they do not have to be like this. A hybrid can be any combination of technologies used together. This is one place where I hope to spark the imagination of my students because there are so many possible combinations.

The hybrid engines that are in common use today work on two different principles. Either the electric or the gasoline engine will be primary. In my hybrid, I drive a Toyota Prius, the electric engine is the primary engine. This means that the electric motor is the only motor running until I demand more power than the electric motor can give, or the battery is drawn down too far. In either case, when the electric motor can not handle the job, the gasoline motor turns on. Furthermore, I have two systems of brakes. One is a generator, which uses the rotary motion of the axles to generate electricity to recharge the battery. The other is the ordinary type of brakes. All of this means that if I am traveling slowly, for example in rush hour traffic on I-95, I am using far less gas than my fellow motorists because my gasoline engine is not running. The other theory of hybrid technology uses a gasoline engine, which is supplemented at higher speeds with the electric engine. Both methods work well to reduce the consumption of gasoline, but both methods still rely on gasoline to function. If hybrid technology is going to be used for the long term, it will need to stop using petrochemicals.

Funky Materials and designs

This section explores ways that currently available engines are being used in combination with new automobile body designs to produce greater efficiency. This section also explores how new materials are being used in old designs to again increase the efficiency of currently available designs.

Innovative designs

There are many innovative designs which have come on to the market in the past few years. I suspect many more will follow as the cost of petroleum products continues to rise. However, here are a few that are somewhat popular now.

Minis

Compact cars have been on the market for many years and have been marketed as being more gas efficient than larger vehicles. However, this design theory has been taken to a new level with the introduction of mini cars. These cars are much smaller even than the compact cars currently available and use far less gas because of their lower mass. They have gained some popularity in Europe where they have specially designated parking spaces in some cities. However, they do have some downsides to them as well. For one individual, they potentially can work well, unless the individual is tall or very broad. These vehicles can not carry large numbers of people or large amounts of baggage and goods. These issues are somewhat similar to those that are seen in animal transportation. Finally, mini cars are lighter than standard sized cars, which means that in a contest of physics that is a traffic accident, they and their occupants are likely come out worse than a standard sized car. This is a good way to introduce the concepts of impulse and momentum to students who will not have studied these concepts yet.

Drag reduction

The use of streamlined design features on cars to reduce drag has been practiced for many years, particularly in race cars. However, several new designs have taken this idea to extreme limits. This is another area where I hope to spark student imagination. It is also a good place to talk about air and water resistance. After all, drag reduction is done on boats, too, and many cities including New Haven could potentially use boats to increase the efficiency of their inner city transit systems.

Innovative materials

Like design innovation, materials innovation seems to have accelerated in the last few years. Again, I suspect that this field will continue to grow and change, but here are a few ideas to begin with. Please feel free to augment this section by adding comments to the website edition of this unit.

Weight reduction

In recent years, there have been a number of new materials that have been developed and several old materials that have been used in new ways which reduce the weight of a vehicle. Reducing the mass of a vehicle also reduces the amount of energy needed to move the vehicle. For example, aluminum has been used to replace iron in some engine blocks. This substitution makes the engine block, arguably one of the most massive parts of vehicle, much lighter. Less mass means less fuel is combusted. In many vehicles, the bumper covers are now made of composite materials that are much lighter than the old metal bumper covers. Additionally, the composite does not rust the way the metal ones did. These are just a few examples, but there are many more. New ones keep coming out because it is a simple way for car manufacturers to increase the overall efficiency of the vehicle without reducing the power put out by the engine. Again, this is a place where I think the students will enjoy coming up with some new innovations for their vehicles.

Friction Reduction

Another innovation in the field of materials sciences is the introduction of new lubricants which reduce the amount of friction between moving parts of the engine. The new lubricants range from reformulated oils to new substances all together like forms of carbon like graphite. Again, this is an area where car companies can improve overall efficiency without compromising the power output of the engine.

Student design project

This project will be set up like a webquest. It may actually turn into a webquest if I have time before I teach it. The order in which we are expected to teach the curriculum has not yet been set. If it does become a webquest, it will be located at my website http://mrsesty.tripod.com, which is maintained only to the extent that I am using particular sections of it in my classes. Incidentally, there are other interesting projects on the website, but be forewarned that there may be broken links. Regardless of whether or not they have a webquest when they get to this unit, the students will be asked to prepare for a symposium to present a strategic transportation plan to the city. In order to participate in the symposium, the students will need to become an expert in one or more, depending on class size, type of transportation technology. Just like participants in a real symposium, the students will be asked to present papers on their research. Finally, again like the real world, the students will be asked to put together a plan to present to the city for a new more efficient transportation system.

The Overview

Before being sent out on their own to do research, I plan to give an overview of all of the technology described in the two previous sections, old school technology and new school technology. Ideally, I would be able to do this as a PowerPoint presentation with a few hands-on activities. In the real world, I will probably end up presenting this section at the board with the same hands-on activities. In any case, this section is here to give some ideas for the hands-on activities. The two topics that I anticipate will be most difficult for my students to comprehend are combustion chemistry and the complex workings of combustion engines.

The chemistry of carbon is one of the more important topics that my students learn in integrated science. Understanding the stoichiometry required in the chemistry of carbon is one of the more challenging aspects of this topic. My students have trouble comprehending how and why the chemicals on the reaction side are rearranged to form the chemicals on the products side of the reaction. I have invented a game in my classroom that seems to help the students sort out what happens. The game is the reaction store. It is based on playing store, like I did as a child. The game starts with a reaction written on the board. I will put together examples of the chemicals used in the equation, at least at the beginning, so the students will be able to see what they look like. In our game, I am the storekeeper; I keep all of the chemicals that are found on the reactants side of the reaction. The students have to make the chemicals on the products side of the reaction. The students are given scraps of paper to represent money and they must buy their ingredients, their reactants, to use to make their products. The students can buy as much of the reactants as they like, but the students with the most money, paper scraps, at the end wins. Extra bits and pieces left over from inefficient processing cost money to pay for disposal, so the students learn that they should buy only what they need and make sure that the reaction is properly balanced. At the end of the round, we count up how many of each reactant the students "bought" and how many of each product the students made and write the numbers into the equation. This process works well in my classroom because I tend to have small classes, but it could easily be applied to larger classes by breaking the students into groups and having one student in each group act as a shopkeeper. In my room, I use a motley collection of chemical models that I inherited with my rooms, but anything could be used that can be recombined to form products from reactants. Legos come to mind as well as scraps of paper, and erector sets and tinker toys, almost all of which have the added benefit of being less expensive per piece than chemical model kits.

The complex workings of a combustion engine are far easier to explain if you have a model or a picture. I do not have a model yet, but I do know where to find an excellent picture. The book How to keep your Volkswagen alive has marvelous illustrations both of the engine and of the engine as a part of the whole vehicle [10]. The engine illustration is also very well labeled. Precisely how you get multiple copies of an illustration from one copy of a book, I leave to your own ingenuity. I plan to have my students color the parts of the engine and take notes on them as we go through the engine. I suspect that it will take a few days if we do it in detail, but I think the added knowledge will be of particular benefit to my class. The only way my students can enter our school is with proof of pregnancy, so I have a class of girls. Most of my students do not drive, but some have been enrolled in a votech program training to be mechanics. At any rate, the comprehension of the basic workings of this ubiquitous technology is likely to be useful in all of my student's lives. If I happen to have a bored or ambitious student along the way, I may offer her extra credit to build a model of a generic internal combustion engine to use in future years.

The research

After being given an overview of the various technologies described in the two previous sections and any new ones that come up between now and when I am teaching the unit, the students will be asked to choose a technology to study. In my class, because it tends to be small, I may ask the students to choose one new technology and one old one. The students will do the research online and in the books that I have found on particular topics.

The students will be asked to write a paper to present to our symposium on the costs and benefits of the technology and put together some sort of visual representation of a new idea for their type of technology. The paper will be about one page in length and will be typed so that it can be put together with the other papers into the proceedings of our conference. The paper will focus on the economic, environmental, social, and societal costs and benefits of the technology they have chosen to study. For example, a car has economic cost in that it must be purchased or leased and maintained, environmental costs in that it produces carbon dioxide, social costs in that most people drive alone, and societal costs in that roads must be maintained. However, it has economic benefits in that a person can work further from home for more money, environmental benefits in that they can be less harmful than other forms of transportation, social benefits in that they confer social status, and societal benefit in that higher social status makes happier people. I would expect far more detail from my students, and I may have stretched a few points here in my example, but you get the idea. The students will also be expected to be able to explain how their technology works and prepare an illustration of some potential improvement to their technology.

The presentation

The students will be asked to present their research to the class. Ideally, the students will prepare a short PowerPoint presentation, but I will have to see what our technology situation is when I teach this unit. The presentation allows all of the students to hear about the costs and benefits of the various types of technology and teaches my students useful presentation skills. The students will also be encouraged to take notes on the presentations of their classmates for later use in the symposium. Ideally, the students could be given forms for each type of technology and be asked to write down significant ideas from each presentation.

The symposium

The symposium will require the students to synthesize the information they have gained through their own research and that of their classmates. The students will be asked to come up with a grand scheme for transportation in the city. The only requirement is that they must show how the mix of technologies in their proposed system is an improvement over the current one in the four categories, economic, environmental, social, and societal, that they studied. Ideally, this information could be presented to some important dignitary for appreciative comments. In a class larger than the ones typical in my room, I would suggest two or three symposia. Alternatively, the students could be asked to break up into sub-committees to come up with a solution to issues relating to a particular category.

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