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The Case for Biodiesel with Selected Experiments

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Introduction

"All who have meditated on the art of governing mankind have been convinced that the fate of empires depends on the education of youth." Aristotle spoke very wisely of education. As teachers we have an important trust: to educate our future leaders. While we are helping our students learn we should embrace the larger and more difficult issues as a medium for teaching our students. By constantly addressing larger issues our students will hopefully feel vested in the decisions and also will be better equipped to make decisions when they are ultimately responsible for the choice.

But why global warming? While the actual consequences of global warming will be discussed later, suffice it to say they are disastrous. Unfortunately many people are not aware of the stakes. We need to empower people and help them realize that they can make a difference in the world, even on problems that are global in scale. As Margaret Mead said: "Never doubt that a small group of thoughtful committed people can change the world; indeed, it is the only thing that ever has." And maybe some of those people will come from our classrooms. If we want the world to be a better place, we must start with students. We are in a position to make sure that our future governance takes the environment into account when making its policies. I am not suggesting that this unit should be used at the expense of other processes and skills we are supposed to help our students learn; I am saying that global warming is a good issue to use as a medium for teaching skills that otherwise we would be teaching in other ways. It is an overarching idea that contains most of the ideas that would be taught in a science or other classes. In this way we can make sure our students are learning the things they should, empower them to realize that they can help change the world for the better, help make sure they are aware of one of the major issues concerning the world.

Rationale

This unit focuses mostly on American consumption of fuel for a very important reason: America is the biggest consumer and unfortunately the largest waster of energy. If America cleaned up its act the world would be much better off. Also, because of the scale that America has when it comes to energy, if technologies are introduced here they are very likely to be adopted in other countries. All of the ideas (with numbers and geographies appropriately adapted) could be adopted anywhere in the world.

This unit is designed primarily for high school chemistry, biology, or physics classes. Additionally there are many parts that could very easily be used in a mathematics or social studies class. The bulk of the content is chemistry, but the energy balances and transfers fit nicely in a physics curriculum. Also the way in which the different biological components fit together and the beginning ecological issues go well in a biology class.

The politics involved between different countries and trade balances touched on in this unit would go well in a social studies class, as would the geography and use of land and also how the legislative process works with the repealing and gutting of environmental legislation. There is very little mathematic exploration in this unit, but there are some good algebraic manipulations (mostly in the appendices) that would be very good to practice skills should a group of teachers want to teach an interdisciplinary unit from this.

So what is global warming? Global warming is the increase of the average Earth's temperature. It is absolutely occurring, if there were no global warming the Earth's temperature would be near -25 ?C (calculation in appendix). We also know that Carbon Dioxide (CO_2) increases the effects of global warming and that humans are releasing CO_2 into the atmosphere at previously unprecedented rates. Global warming and its effects are perhaps the biggest danger the next few generations will face.

Unfortunately, many people say that global warming doesn't exist, but anecdotal evidence shows that most of them are supporters of Lamarckian evolution as well. Global warming does exist. Through a simple study of the amount of energy the Earth receives from the Sun we know that if global warming did not occur, the average temperature of the Earth would be near -25 ?C. Since this is not the case, we know global warming occurs. It is our duty as educators to make our students aware of scientific facts. There is a lot about global warming that is known, but there is also some uncertainty, I would encourage letting your students reach their own conclusions based on the facts and the ranges of data known, just make sure that all conclusions can be supported. Is it coincidental that in the past few years there has not been a single peer-reviewed scientific article doubting that humans are adversely affecting global warming, yet in that same span 54% of the articles in the popular press cast doubt on that assertion?(9) Why is it that the scientific community is in complete agreement, yet the American public seems as unsure of this as they used to be about the link between smoking and pulmonary health? I would assert that it is because many people are scared of science and just passively accept other's explanations instead of critically analyzing data; hopefully this unit will help de-mystify the science of global warming, making it accessible to high school students.

Background

The background knowledge presented in this unit contains information well beyond the scope of what the students are expected to learn. This is because much of the things that students will learn will (hopefully) lead to questions which could go in many directions. This unit is relatively narrow, but as an educator you need to be prepared to answer questions that could be all over the place. I will keep what is known for fact and what is assumptions based on trends and data separate, but be aware that there are some conclusions in this unit that the scientific community is only 99% sure of, we do not know them for fact. Another note: there is propaganda that there is much "error" in the experiments and models used to predict the consequences of global warming. Remember that in scientific terminology "error" is more precisely defined as uncertainty. Also, even where there is uncertainty, there is much that we are certain about. We do not know the exact length of a ruler, there is error/uncertainty in even those measurements (matter is constantly moving so its exact length is constantly changing). Saying that the temperature will increase 3?C with an error of +/- 2?C still means that there will be an increase in temperature; and given that range of temperature the seas will raise between 3m and 25m, while yes, we are not sure how much, we do know it will rise and many of the conditions that will cause the 3m versus the 25m rise.

What is Global Warming

So how does global warming occur? Basically, when the rays from the Sun hit the Earth, a lot are instantly reflected, but some are temporarily absorbed then re-emitted. Those re-emitted rays are altered while absorbed (their frequency changes), so when they hit the atmosphere in their way out they are (in large part) absorbed by the atmosphere, then re-emitted, roughly half of it going back towards the Earth. They keep bouncing between the surface of the Earth and the atmosphere until they finally can escape. All the time they are bouncing back and forth, while not warming the planet after that initial bounce, they are keeping the energy in the system higher. The Earth warms when the trapped energy plus the incoming energy from the Sun is greater than the current temperature and the energy released into space. More gases released (like CO_2 and Methane) mean more energy is trapped, leading to an increase in temperature.

Is Global Warming Real

First, let us make sure that global warming is a real phenomenon. Let us say we did not have an atmosphere that caused global warming. That is a fairly simple calculation to do, it involves many things, but the calculation itself could easily be done by an Algebra I or II student. Also, the calculation does not involve assumptions; it is based on First Principles, Laws of physics, and experimental data that are not disputed by the scientific community.

Calculating Global Warming

There are many things that factor into the calculation of the temperature of the Earth absent an atmosphere, among them the energy emitted from the Sun (luminosity), the distance of the Earth from the Sun, and the albedo of the Earth. The amount of radiation the Earth receives from the Sun is effectively constant, there are small changes but they are very minor. Nor is the distance between the Earth to the Sun a constant since the Earth follows an elliptical orbit, but we do know the distance at a given point in time, and the distance can be taken into account when making the calculation. Look in the Appendix for the exact calculation.

Since the Temperature of the Earth is warmer than the calculated -25 ?C, there must be something that is globally increasing the temperature of the Earth. That phenomenon is called global warming.

Albedo

One of the most difficult things is to figure out the albedo of the Earth. Albedo is the ratio of energy that is reflected by a surface divided by the total amount of energy that hits that surface. A perfect mirror has an Albedo of 1, and a perfect black body, something that absorbs all energy, has an albedo of 0. Albedo is the main reason why you feel warmer on the beach when you're wearing darker colors compared to wearing lighter colors. The albedo of the Earth is constantly changing, the clouds shifting; the amount of glaciers and many other things affect the albedo. By doing many calculations we are able to determine that the average albedo of the Earth in 1990 was 0.39. This means that 39% of the energy that hits the Earth from the Sun is instantly bounced back into space. The rest is absorbed, and then re-emitted. If the energy were never re-emitted, then the temperature would just keep increasing until the Earth was as hot as the Sun. Taking into account the amount of energy absorbed by the Earth before it is re-emitted, the Earth would be approximately negative 25 +/-2?C. Of course this is not an exact number, it is possible that the Earth could be as hot as -23 ?C, but that is unlikely. The more likely case is that the low temperature would cause all the water and some other things to freeze increasing the ice cover. Ice, being reflective, would increase the albedo of the Earth causing more energy to be reflected, causing the Earth to plunge deeper into the cold. If all of the Earth's water froze and covered as much of the planet as is currently covered by water or ice today, the Albedo could go as high as .6 or .7, making the temperature of the Earth somewhere between -49 and -65 ?C. These temperatures obviously do not allow life which needs liquid water to exist.

One of the things that is only recently being taken into account at the level it needs to be is how the melting of ice is changing the albedo of the Earth. Ice has an albedo of 0.9. Ocean water has an albedo of 0.08. As ice melts and is replaced with water, the albedo of the Earth is reduced. This causes an even larger increase in the Earth's temperature causing even more ice to melt causing the temperature to rise even more. This vicious cycle is causing the temperatures to rise even more than the direst predictions. As Stephen Colbert said, enjoy any jokes about glaciers while you can because our grandkids may not know what glaciers are.

Cloud Effects and Venus

Clouds also reflect the rays of the Sun, but depending on their composition and where they are they also capture heat. The physics of clouds is not completely understood, so we do not know the exact effect they will have on the temperature of the Earth. What we do know however, is that Venus which is completely covered in clouds (albedo = 0.76) has an average surface temperature of 400 ?C. Doing the same energy calculation for Venus that we did for Earth, Venus should have a temperature near 20 ?C (calculation in appendix). What is different? There are many things that led to Venus being so warm, but the largest is that at 20 ?C CO_2 could not be completely sequestered by the soil. We know all of the previous for fact. But what conclusions can we make? Well, the increased cloud cover did less to reflect the energy than the CO_2 did to trap any energy that did make it in. The CO_2 eventually won out over the cloud cover. We cannot be certain that the exact same thing on Earth would occur (this is one area where there is a minimal amount of scientific debate) as we increase the amount of clouds (by melting ice and increasing water vapor as well as emitting smoke), but it is fair to say that we are making the Earth more like Venus.

CO_2 in the Environment

One of the most alarming things is the rising CO_2 levels. 1958 is when atmospheric CO_2 levels were around 278 parts per million (ppm). Currently the atmospheric CO_2 level is 381 ppm. We know that humans are the cause of that increase. All of the evidence points out that when CO_2 levels rise the temperature rises (see Figure 1). What we do know is that the last time CO_2 was at this level was 3.5 million years ago and the last time it was higher was 50 million years ago. The temperature of the Earth 3.5 million years ago was about 3 ?C warmer, and 50 million years ago the Earth was about 5?C warmer. There is a lag however; it takes a little bit for the Earth's temperature to catch up with the level of CO_2. The CO_2 does not directly heat the Earth, it just causes more of the Sun's heat to be trapped, so it takes a while (10+ years) for the temperature to equilibrate to the new atmosphere.(9)

Occasionally people are audacious enough to say that there is no link between the rise in CO_2 and the rise in temperatures. They even make scientific/philosophic arguments for this, that there is not a causal relationship between the rise in CO_2 and the rise in temperature. One can also make an argument that is not technically incorrect that if you hit a pool ball with a cue stick and the ball moves that the cue stick was not necessarily the cause of the ball moving; after all causality is still only a theory. There are billions of pieces of anecdotal evidence that point out that hitting a pool ball with a cue stick will make the ball move, but there is no proof. Well, you know what, even though there's no proof that hitting a pool ball with a cue stick the ball to move, and there's no proof that rising CO_2 levels are the cause of the Earth's temperature rising, I'll put my money on the fact that the pool ball will move when I hit it with the stick.

Natural CO_2

Another effect of the melting ice is an increase in natural CO_2 emissions. Our emissions of CO_2 are causing natural sources to emit more. This is because there is a lot of biomass frozen in the ice. As this ice melts the biomass will be able to decay, releasing CO_2 into the air. Even though this CO_2 is coming from natural sources, it is man's intervention that is causing this release of CO_2.

Sea animals also store CO_2 for us. Coral reefs and the shells of creatures have a lot of CO_2 stored in them. Unfortunately the gases we are releasing into the air are changing the pH of the oceans such that coral reefs are being killed en masse. If coral reefs do not continue to grow, a lot of CO_2 will no longer be able to be trapped causing an even bigger increase in atmospheric CO_2. Also at low enough pH's shellfish can not make their shells. This means that if we do not stop emitting certain gases all shellfish could conceivably be killed. It is calculated that if the CO_2 levels in the atmosphere quadruple (which could happen in less than a century at the current rate we are increasing our emissions) the pH of the ocean could drop to levels where unless the shellfish and coral evolve, they will all die. Preliminary evidence suggests that they will not survive as most coral reefs are dying or dead already. Yes, shellfish did not die when CO_2 levels were this high millions of years before, but the rise of CO_2 was much slower then, the animals had a chance to adapt. The calculations of pH and the extinction of the shellfish and coral are not 100% guaranteed, they are the most likely scenario, but not guaranteed.(1)

Another sink of CO_2 that will become less effective is the oceans. Water can trap gas. As it warms it traps less gas (imagine a carbonized beverage, while cold it keeps it's bubbles, but the gas fizzes out as the liquid warms). As we heat our oceans the gas that was previously trapped is being emitted. The amount of CO_2 humans produce is nothing compared to the amount of CO_2 trapped in the oceans. If we keep messing around with the environment the ocean could start giving off that trapped CO_2 in larger quantities. This large dump of CO_2 into the environment would be catastrophic. There is more CO_2 in the oceans than in the atmosphere. This is likely to be the obvious sign that we're past the point of no return, the canary in the coal mine died, if the oceans dump a significant amount of the CO_2 they're trapping into the atmosphere it will likely take centuries to reverse the damage we've done to the Earth.

The rocks of the planet similarly have a lot of trapped CO_2; in fact there are orders of magnitude more CO_2 in the rocks compared to the oceans and atmosphere combined. The release (or capture) of CO_2 by rocks is a very slow process, thousands of years could pass before the amount trapped would naturally change.

There are other greenhouse gases, methane most notably, but even though 1 mol of methane traps a lot more heat than 1 mol of CO_2, since there's hundreds of times more CO_2 than methane (~370 ppm vs. 1.7 ppm), it is on CO_2 that we most heavily concentrate. Also, most measures that reduce CO_2 also reduce methane.(17)

Temperature Variance and Water

Even a low-ball 2?C change could be disastrous. 2?C would be enough to melt most of the glaciers and ice caps. There is enough water trapped on Greenland alone to raise the ocean water 6 meters, not to mention the Antarctic ice sheets. But what will be worse is the thermal expansion of water. Remember, water expands when it warms beyond 4?C . An average of 2?C may not seem like much, but warmer waters could expand as much as 0.11%. Again, this may not seem like much, but when you multiply that tenth of a percent by all of the water in the oceans you're talking about 3 million cubic kilometers added volume (calculation in appendix), a rise of 9m, and that's not including any water that's melted in the past decade. A more conservative 2m rise is expected in the immediate future, but that 9 meter rise is likely within the next century if we do not drastically cut our emissions.(16)

Weather Patterns

Another effect that the rising temperature could have is a complete change in weather patterns. Warmer water has two major weather consequences: Storms will be more severe and there will be more droughts in the interior of continents. The first, more severe storms is simple to understand, warmer water has more energy (temperature is simply a measure of thermal energy), since there's more energy to be released, the storms will be more severe. Katrina, for example, was only a level 1 hurricane when it went over Florida, but in the time it spent in the Gulf Coast it changed into a level 5 hurricane before making landfall in Louisiana and Mississippi. Historically, a storm spending that amount of time over the water at that time of year should not have become that strong, but since the water was warmer than it should have been the storm was stronger. There is also an increase in the number of severe weather incidents. For the past few decades, as long as this information has reliably been kept, the warmest years have had the most severe weather events (hurricanes, tornadoes, etc…). So the increasing temperature is not only making the serious weather events more severe, they're also happening more frequently. So if there are more hurricanes and the like, then how are there more droughts? Well, since there is more energy in storms and other weather events when they hit land, they hit the critical point that allows them to precipitate quicker. The severe droughts currently being experienced by inland Africa and the central United States are most likely linked to this phenomenon. Additionally the increased temperature would cause more water to evaporate from the ground, resulting in an expected 60% increase in desert area.(9)

It is slightly counter-intuitive, but just as global warming causes warmer summers, it also causes colder winters. This is because there is more energy in the environment, the increased energy causes the extremes (both hot and cold) to be more extreme.(9)

Another potentially catastrophic occurrence is the stopping of the Gulf Stream. The Gulf Stream is the current that pulls warm water from the Gulf of Mexico around the Western edge of Europe and distributes waters around the world. The Gulf Stream is driven by the temperature gradient created by the warm waters near the equator and the glaciers in the North Pole and on Greenland. If they melt too much, the Gulf Stream could stop. Millions of years ago this happened when the Glaciers on North America melted at the end of an ice age, and it took thousands of years for the Gulf Stream to restart. The Gulf Stream is already slowing! In the past 12 years the Gulf Stream has weakened by 30%.(7) The most apparent issue with this is that the Gulf Stream is what keeps Western Europe at the climate it is. Rome is roughly the same latitude as Boston, but it is much warmer. London's latitude is pretty far into Canada, yet is relatively warm. A lot of Europe will end up frozen even as the rest of the world is melting. The results of this are not fully known. We know that the Gulf Stream shutting down (as it is likely, but not definite to do) would plunge Europe into an ice age, but the shutting down of the Gulf Stream could also allow the poles to cool again. The streams are a major contributor for the poles to warm more than the equator, so if they shut down maybe the poles will cool a little bit (with the equator staying even hotter). Perhaps the poles will re-freeze, and the additional deserts the extra heat at the equator would cause together will start reflecting more energy allowing the Earth to cool a little bit. We do not know, but it is likely that if these events do happen it will be centuries before the environment we have thrived on could be restored despite these mitigating effects.

Biomes

Already as the planet is warming many animals are changing where they live. In the case of butterflies moving further north this may seem harmless, but there are issues with other animals. Mosquitoes, for example, will pose a serious issue. Many cities in Africa were placed at certain latitudes or elevations in part to avoid mosquitoes and their diseases. As things get warmer mosquitoes travel further from the equator and also to higher elevations. This is a relatively new phenomenon that people are not ready for. Incidences of malaria have increased roughly 30% in the past few years. People are not protecting themselves from malaria because malaria was previously unknown where they live. Other diseases (both animal borne and bacterial and viral) are expanding the areas they affect as their biome is expanded. (9)

Official Response

Unfortunately when the White House says things to the effect that global warming could even be good, they do not take most known information into account. The only thing they look at (to date) is how the average temperatures are affected. Since it will be warmer, land farther north could be used for farming. They don't consider the other effects like the rising seas (which IS what happens when the temperatures increase) and changing climate patterns and changing biomes. All of these events have been recorded, now it's just a matter of people outside the scientific community taking notice of the data and the trends it shows.

The Case for Biodiesel

Sources of CO_2

One of the easiest things that the world can do to help alleviate the problems of global warming is to cut down CO_2 emissions. In America there are two main sources of emissions. The first is the transportation industry. Most Americans of age own a car and drive it polluting the environment. The two things that make this worse in America than most other countries is the fact that we drive cars by ourselves instead of car-pooling or taking public transit and the ridiculously low mileage we get in our vehicles. Foreign cars get 50% more mileage per gallon than American cars. Knowing this the American public has started buying fewer and fewer American cars, yet the American auto industry is trying to keep the required MPG at the lowest in the world.

And that's just the cars; SUV's are not considered cars.(5) GM has successfully lobbied the government to get SUV's classified as trucks, meaning they can get even fewer miles to the gallon. We are wasting fuel at a ridiculous rate. A few months ago the Secretary of Energy for Bush gave a speech on energy conservation. He flew on a private jet to California, then took an SUV to a speech he gave from said SUV without turning off the engine, then flew back on another private jet flight. In giving his speech on energy conservation he wasted more energy than most people in the world consume in 3 years. Despite this, the transportation industry is not the biggest consumer of fossil fuels. Fully 70% of the United States energy is put into the power grid from the burning of fossil fuels, primarily petroleum and coal. The energy industry is a huge polluter, having in the past 5 years successfully gotten the government to change laws so the energy industry can pollute more than they could at any time since 1970. There are other sources of gaseous emissions, but these are the two largest. Additionally jets and other fuels that are now primarily petroleum could possibly be modified with Hydrogen Peroxide, but the emissions from that might not be any better and safety concerns with using rocket fuel for planes is beyond the scope of this unit. If we cut down our emissions our ecosystem would have a chance of recovering.

But what can we do? Americans use a lot of energy and want to be able to drive places without carpooling. Is there a way to cut emissions without cutting our energy consumption? Yes.

Why Biodiesel

Biodiesel could be a key ingredient to helping save our environment. It is not a panacea, but it will definitely help. Biodiesel cuts CO_2 emissions by over half compared to the emissions of gasoline. It still emits carbon dioxide making it only a band-aid, but it is a stop-gap measure until alternative energy sources can be better harvested. I think biodiesel is a viable source of energy because there are little or no alterations that need to be made to our cars and power plants for it to be used. The consumer does not need to make major changes, just the suppliers. Biodiesel is diesel that is produced (process to be discussed in experimental section) from vegetable oil instead of petroleum oil. Biodiesel is not the final solution to our energy/environment conflict, but it is a good first step to wean ourselves off of petroleum based fuels.

Throughout this unit there will be reference to theoretical and actual values. Wherever possible actual values (either collected from industry or experiments) will be used, although mention of theoretical values may be made because as we start doing things in larger scale processes become more efficient, but sometimes there is not enough data so theoretical calculations must be made. This is especially true when talking about calculations of capacities in foreign countries, for example how efficient is the drilling for oil in the Middle East? We do not know for sure, but we can compare it to what the numbers were in similar climates in America when the oil was similarly plentiful. Is this exact? No, but it is very close and will be a decent ball park figure. Since some of the data is not exact there will need to be a very large difference between biodiesel and petroleum oils to be sure, so the calculations made are using the numbers that are the least favorable to biodiesel although reference to the other calculations is made. So if the most petroleum friendly numbers are used, and there are shown to be marked environmental and economic advantages to biodiesel, we can be sure that biodiesel is preferable to petroleum oils.

Energy Balance

In order to figure out how much Biodiesel helps the environment we need to look at energy balances. The first thing to consider is how much energy it takes to produce fuel. The oil in the ground does not end up in your car (or heater or other use of oil) without any effort. Many things must be taken into account.

Let's first look at gasoline. Gasoline must be pumped from the ground, refined, transported, and then finally it can be burned to release energy. Depending on where the oil is gotten from sometimes things like sand and water must be filtered out. And if the oil is in sand pumping it out is much more difficult. If the oil is gotten from frozen areas it must be transported (see permafrost melting section for discussion of transportation) to areas where it will be refined and used. All of these things take energy. The technical name for this calculation is Energy Returned on Energy Invested (EROEI). It is estimated that back in the 1930's we had to put one joule of energy into producing enough gasoline to release 100 joules of energy (EROEI of 100). By 1960 that same one joule would only produce enough gasoline to release 50 joules of energy (EROEI of 50). That reduction is mainly due to the fact that we were using oil that is harder to pump, all the oil we could easily get to was used. By 1998 the average EROEI of oil consumed in America was 10, and it is calculated that the average EROEI in 2004 was 5. We are using all the oil that is easy to get to, and that ratio is going to get worse and worse as it gets harder to pump oil. Some estimates have that ratio going down to 2 or lower in the next decade. In addition to the lighter oil and non-sandy oil being consumed, the oil in the colder areas will be harder to get. Currently most of the roads in Alaska and the pipelines depend on the soil being frozen. They are placed on permafrost and as that soil unfreezes the roads become undrivable and the pipelines crack from sinking. Entire pipelines and roads will have to be re-laid. Diesel does not have the same EROEI as gasoline, but it is similar. Diesel has more energy per gallon than gasoline and the engines are more efficient. The increased efficiency of the engines (gasoline engines require 4 strokes to propel the car while diesel engines require 2 strokes) was not taken into account because while this is an advantage to Biodiesel over gasoline, it is not an advantage to Biodiesel over petroleum diesel.

Calculating the EROEI of Biodiesel is a little bit trickier. The main thing that affects this is where you get your vegetable oil. The main sources of vegetable oil that are being used are soy, corn, and used cooking oil. Used cooking oil (called yellow grease) is the best to be used by far, with soy and corn oil virtually the same but behind yellow grease. Yellow grease has a theoretical EROEI of 35.7 since the expense of turning the vegetables into oil is ignored because that oil was produced and used for its initial purpose, but realistically has an EROEI of 6.34. Unfortunately there is a limited supply of yellow grease; only about 2 billion gallons of yellow grease and the like per year are produced in America today. This is helpful, but not enough considering the US consumes about 150 billion gallons of petroleum a year. We must look at other sources for Biodiesel.

The EROEI of Biodiesel from soy and corn is variable; it depends mostly on where the crop is grown and how much fertilizer must be used. I will focus mostly on soy Biodiesel because soy is a crop that is less exhaustive on the soil than corn. The EROEI of soy Biodiesel could range anywhere from 1.2 to 7, but 3.4 seems to be the most accepted low estimate.

Materials Balance

Now that we have figured out the energy balance, let's look at a materials balance. More specifically, what are the CO_2 emissions of the fuels? Theoretically 3.96 Liters of gasoline produces 8.8 Kg of CO_2, that same amount of diesel produces 10.1 Kg, and that same amount of Biodiesel produces 2.6 Kg! Experimental data is skewed even more towards Biodiesel, with gasoline emissions being 12.6 Kg of CO_2 and Biodiesel emissions being 2.7Kg and other experiments showing an even bigger differential. Even using the conservative estimates though, Carbon Dioxide is reduced by 54% (calculations in Appendix) using Biodiesel (experimental data from the Department of Energy and United States Department of Agriculture showing reductions 78% or more). Also, remember that the plant used to make the biodiesel is soaking CO_2 from the air, the CO_2 that is released, making biodiesel virtually carbon neutral and that one Liter of biodiesel gets you further than one Liter of gasoline.

Other molecules like carbon monoxide, soot, methane, and others are reduced substantially, anywhere from 37% to 84% Sulfur oxides (SO_x) are theoretically reduced by 100% (experimentally reduced 99.9997%). SO_x are particularly dangerous pollutants. Not only are they one of the main molecules that lead to acid rain, but they have also been shown to cause bronchitis, emphysema, heart disease, and are occasionally carcinogenic. Cutting out SO_x could help mitigate the lowering pH of our water supplies. There is one down-side to biodiesel…there is an increase in nitrous oxides (NO_x) emissions. There can be as much as a 10% increase in NO_x emissions, but 8% is more common. NO_x is also a precursor to acid rain. The decrease in SOx emissions more than makes up for the increase in NO_x emissions, but that doesn't even have to be taken into account. Knowing the release of NO_x and SO_x gases is bad for the environment catalytic converters were put into cars and power plants to take out those gases. They currently are designed to take out a high percentage of both, but if they were changed to effect only NO_x gases they would become even more efficient and cheaper. They also would last longer, meaning you would have to replace the catalytic converter in your car even less often than you do now.(14)

Waste of Petroleum vs. By-Product of Biodiesel

Another difference between biodiesel and petroleum oils is the amount of solid waste in their production. The production of biodiesel causes twice as much solid waste; however this is a good thing. The solid waste of biodiesel production is almost entirely fertilizer. It is biodegradable and can actually be used to make soil more fertile, increasing the EROEI of biodiesel even further, or it can be used to produce other alternative fuels like celluloid ethanol which cuts greenhouse gases by 85% (also there is currently enough farm waste to reportedly make enough celluloid ethanol for 25% of American transportation). There is some hazardous waste from biodiesel, but it is 96% less than petroleum oils. Disposal of waste from petroleum refineries is a major problem, quite often the waste is carcinogenic, and it is always harmful and must be stored similar to nuclear waste. This is not to say that the petroleum waste is as bad as nuclear waste, it doesn't need to be stored as long; but when you're talking about billions of Kg's instead of a few Kg's, there is a major issue. Biodiesel does not have this problem, almost all of its waste could actually be considered a useful by-product that can be sold itself or turned into more fuel.(14)

Economic/Geopolitical Safety

An additional advantage is that if we switch to biodiesel the US could be completely self sufficient as far as fuel is concerned. We will not have to worry about the whims of other countries that might want to make more money at the cost of the American consumer. Since all of our oil is produced domestically we would not have to import any oil. Also, when we are gouged at the pumps at least the money will be reinvested into our economy more broadly to farmers instead of into the few pockets of the oil magnates. This would also create many jobs for Americans, even further helping our economy. Since we would not be as concerned economically with other countries we could possibly become even more insular, but a cost benefit analysis (in my mind) would say that we're better off ignoring a world than not having a world. This is a tough sell though, because a lot of fortunes would be at risk, many people with power in America have a lot to earn from instability and petroleum.

Possibly more important than the direct economic issues is the fact that we would be self sufficient as far as energy is concerned. We would not have to depend on the good will of other countries to keep our energy supply and the ability to trade. At $70 a barrel, domestically supplying oil would decrease our trade deficit 448 billion dollars, 61.7% (calculation in Appendix).

Is There Enough Land

But is this practical, how difficult is it to make biodiesel and is there enough land to grow the stuff to make biodiesel? The United States consumes about 20.6 million barrels of gasoline a day, and each barrel makes approximately 19.5 gallons (leaving 22.5 gallons of waste and other by-products) meaning that the US consumes nearly 150 billion gallons of petroleum fuels a year (calculation in appendix). Each acre of land devoted to making biodiesel can produce enough crops for 55 to 200 gallons of fuel depending on how arable the land is and the crop chosen. This means that we would need 3 billion to approximately 750 million acres of land (or less if optimum figures are used) devoted to making biodiesel. This is a lot, but not an impossible amount. Currently the United States government pays people to not plant crops on their land in order for the prices of crops to be higher, there is enough land in that situation or is otherwise lying fallow to develop about 60% of the biodiesel needed. Other land could be converted or used for dual purposes (we're losing about 100 million acres of farm land to urban sprawl a decade), and also soy can be grown on parcels of land in places like New Mexico and other areas that normally are not thought of as arable. Additionally, there is more than enough land in Mexico that is not being used on which soy could be grown. This of course loses the possibility of America becoming completely independent of foreign governments as far as our fuel is concerned, but would you rather depend on the Middle East for fuel or a country with whom we share a border?(2)

Methods

I strongly believe in a hands-on approach to learning. While I will be focusing mostly on the scientific concepts, there are obviously many mathematic and social implications that could be explored. I want my students to learn mostly through laboratory and case studies. Many of the energy and materials balances can be explored using case studies, possibly partnered with a mathematics teacher. The amount of land and economic issues would be a better fit for social studies, but would not be entirely beyond a science case study. After and between doing the case studies, I want my students to be doing laboratory experiments. Lots of experiments. Pre-lab questions are incredibly important as they help make sure the students are in the right frame of mind as they do the experiments. While doing the laboratory reports I will initially have very leading questions, but as the course progresses I hope my students will be able to deal with more open-ended questions. The leading questions are checks to make sure that things like chemical bonds, electron interactions, etc… are understood, and the free-response and open-ended questions will both help as a dipstick into their understanding of the concepts and hopefully spark some further connections within the students' minds. For example I remember single replacement and combustion reactions from the amount of H_2 as a student I made and burned from Zn and HCl. Doing experiments with pre-laboratory questions and laboratory reports is much more effective making sure students learn and retain information than simple chalk and talk. And whenever experiments are not an option, case studies are the next best option.

Laboratory #1

Making biodiesel is a very simple process. If you are making it from yellow grease it's even easier. First go to a restaurant and ask them for some of their used oil. They usually have to pay people to take it away, so most places will give it to you for free. If you're making it from scratch it's a little bit more complicated. Here is a lab you could do with your kids, a step by step guide to how to make biodiesel. Depending on the class you're in you could focus your questions on the energy transfer, material transfer, or changing bonds.

The first step when making it from yellow grease is to strain it to get out any food particles that may have been in it. This is most easily done by running the oil through nylon stockings but other things can be used.

The next step is optional, sometimes people want to boil off water that is in the yellow grease. It is usually not necessary, but it can be done. To do this heat the oil to 100 ?C and stir until bubbling stops. If you do this, be careful to keep stirring because you do not want water that may be present to bubble up in large bubbles. After the bubbling is almost finished, raise the temperature to 130 ?C and stir for 10 minutes. The oil itself will not boil or catch fire at this temperature. After the ten minutes at 130 ?C let the oil cool.

The next step is by far the most sensitive. Take 10 mL's of isopropyl alcohol and add 1 mL of the oil. Add 2 drops of phenolphthalein solution to the mixture. Then add 1g of lye to 1L of deionized water. Very carefully add measured amounts of the lye solution to the oil solution. If you can get them, burettes measured to at least a 10th of a mL are best, but anything that measures to a 10th of a mL works. Slowly add drops of the lye solution (stirring between each drop) until the oil solution turns pink for a few seconds. This indicates a pH of around 8. You can expect to use about 1 to 4 mL's of lye depending on how the oil was previously used.

Next you take the number of grams of lye solution used and add the number 3.5. You then multiply the sum by the number of Liters of oil you plan on processing. The answer is the number of grams of lye you'll need.

Then you mix .2L (20% by mass is the exact amount needed, but using volume is good enough unless you're planning on doing this commercially) of methanol with the lye and stir. Be careful with this solution, it is very basic. If it touches your skin you will not feel the burn that is occurring, but continue to wash for at least 15 minutes. Wear gloves and other protective equipment. Also, do not use plastic containers. Real glass or stainless steel is recommended from here on out.

Next heat your oil to 50 ?C. Then use a stirrer (a piece of wood or a metal paint stirrer attached to a variable speed drill works well, but you can use whatever) and adjust the speed so that a vortex is just appearing on the top of the oil while keeping the oil heated. Once the stirrer is set add the lye/methanol solution (sodium methoxide) and keep the contraption going for about an hour (30 minutes is probably sufficient, but to be on the safe side…). Then let the liquids sit and cool for approximately 8 hours.

You now have approximately 70% biodiesel (which should be on the top and darker in color) and 30% glycerin (which should be on the bottom and lighter in color and may solidify). You can decant the biodiesel and if the glycerin has solidified heat it up to near 38 ?C to pour out. If you are doing this on a large scale you may want to put a pour spout on the bottom of you container.

Your biodiesel is ready to use. The glycerin can be distilled into pure glycerin, allowing you to reclaim most of the methanol and lye, but this procedure is a bit more complicated and beyond the scope of this unit. AP chemistry teachers may want to use this as an additional lab to find triple points and PVT curves and to learn distillation.

Laboratory #2

Take a water thermometer and break off one end. Very briefly hold it under a flame to smooth the edges, but do not allow it to reseal.

Then measure the diameter of the opening. Using the calibrations on the side, calculate how much the water expands to as it increases one degree.

Laboratory #3

Take multiple bottles and place a thermometer that completely fits in them inside the bottles. Then fill the bottles with water and hold them submerged in a tank that is also filled. Use a hose and pump various gases (either with a gas tank or as byproducts from experiments in Erlenmeyer flasks, HCl and Zn mix nicely to make Hydrogen) into the bottles to displace the water.

When all the water is out of the bottles they are filled with the gases you want (I would recommend using at least CO_2, O_2, N_2, and air) seal the bottles. Then leave the bottles overnight (or longer) under in light.

Read the thermometers and see if there is a difference. Make sure the thermometer is very good, because while there is a difference between most of the bottles, it is not a huge difference given the time scales we are dealing with.

Laboratory #4

Take a carbonated beverage and pour equal amounts into 2 Erlenmeyer flasks and stop them with a single holed stopper with tubing attached. Heat one of the flasks to 80?C for about 15 minutes while keeping the other at room temperature.

Then attach a gas pressure gauge to the tubing. Heat both bottles to 80?C for 10 minutes. There should be a higher pressure in the previously unheated flask because the CO_2, that was previously unreleased will come out.

If you do not have a gas pressure gauge to use, you can trap the escaping gas in a water filled bottle as in Lab 3. Also, instead of heating one of the flasks, you could leave one flask out overnight and the other in a fridge overnight, but if you do this make sure your building does not get too cold overnight.

Laboratory #5

Take many transparent containers and cover (or paint) the bottoms and sides of each in different colors. I would recommend having at least one black, one white, one green, one dark blue, one yellow, and leaving two transparent. Place a thermometer in each and put the lids on all of them except one of the transparent containers.

Place the containers underneath heat lamps (try to make sure that an equal amount of light is hitting the tops of each of the containers to make sure the light gets in equally) overnight or longer. See the temperature difference in each container.

Appendix

Temperature of the Earth Without Global Warming

$$\frac{L}{4\pi d^2} \times \pi R^2 \times (1 - A) = 4\pi R^2 \sigma T^4$$

$$\frac{L}{4\pi d^2} \times (1 - A) = 4\sigma T^4$$

$$\frac{L}{16\pi d^2 \sigma} \times (1 - A) = T^4$$

$$\sqrt[4]{\frac{L}{16\pi d^2 \sigma} \times (1 - A)} = T$$

$$\sqrt[4]{\frac{3.827 \times 10^{26}\,\mathrm{W}}{16\pi \times (149.598 \times 10^9)^2\,\mathrm{m} \times 5.67 \times 10^{-8}\,\mathrm{W{\cdot}m^{-2}{\cdot}K^{-4}}} \times (1 - 0.4)} = T$$

Temperature of Venus

Where Ls is the luminosity (brightness) of the Sun, Π is the ratio of the circumference of a circle to the diameter, d is the distance from the Earth to the Sun, R is the radius of the Earth, A is the albedo, s is the Stefan-Boltzmann constant, and T is the temperature of the Earth.

Temperature of Venus Without Global Warming

$$\sqrt[4]{\frac{L}{16\pi d^2 \sigma} \times (1 - A)} = T$$

$$\sqrt[4]{\frac{3.827 \times 10^{26}\,\mathrm{W}}{16\pi \times (109 \times 10^9)^2\,\mathrm{m} \times 5.67 \times 10^{-8}\,\mathrm{W{\cdot}m^{-2}{\cdot}K^{-4}}} \times (1 - 0.76)} = T$$

Water Thermal Expansion

$1400000000\,km^3$ average Temp. 10°C

Density of Water at 10°C = .999700

Density of Water at 12°C = .999498

$1400000000 \times .999700 = 1395800000$

$$\frac{1395800000}{.999498} = 1403096100$$

$1403096100 - 1400000000 = 3096100\,km^3$

Volumetric Expansion $3096100\,km^3$

Surface Area of Oceans = $361254000\,km^2$

$$\frac{3096100}{361254000} = .009km$$

CO_2 Reduction of Biodiesel Over Petroleum

$$\frac{2.7kg}{8.8kg} = .31 \text{ emission ratio}$$

$$\frac{3.4}{5} = .68 \text{ energy ratio}$$

$$\frac{.31}{.68} = .456 \text{ emissions with energy taken into account}$$

$1 - .456 = .54$ reduction

Land calculation

150000000000 gallons of petroleum fuel used a year

1 acre of land yields 55-200 gallons of biodiesel

$$\frac{150000000000gal}{55gal/acre} = 750000000acres$$

$$\frac{150000000000gal}{200gal/acre} = 2730000000acres$$

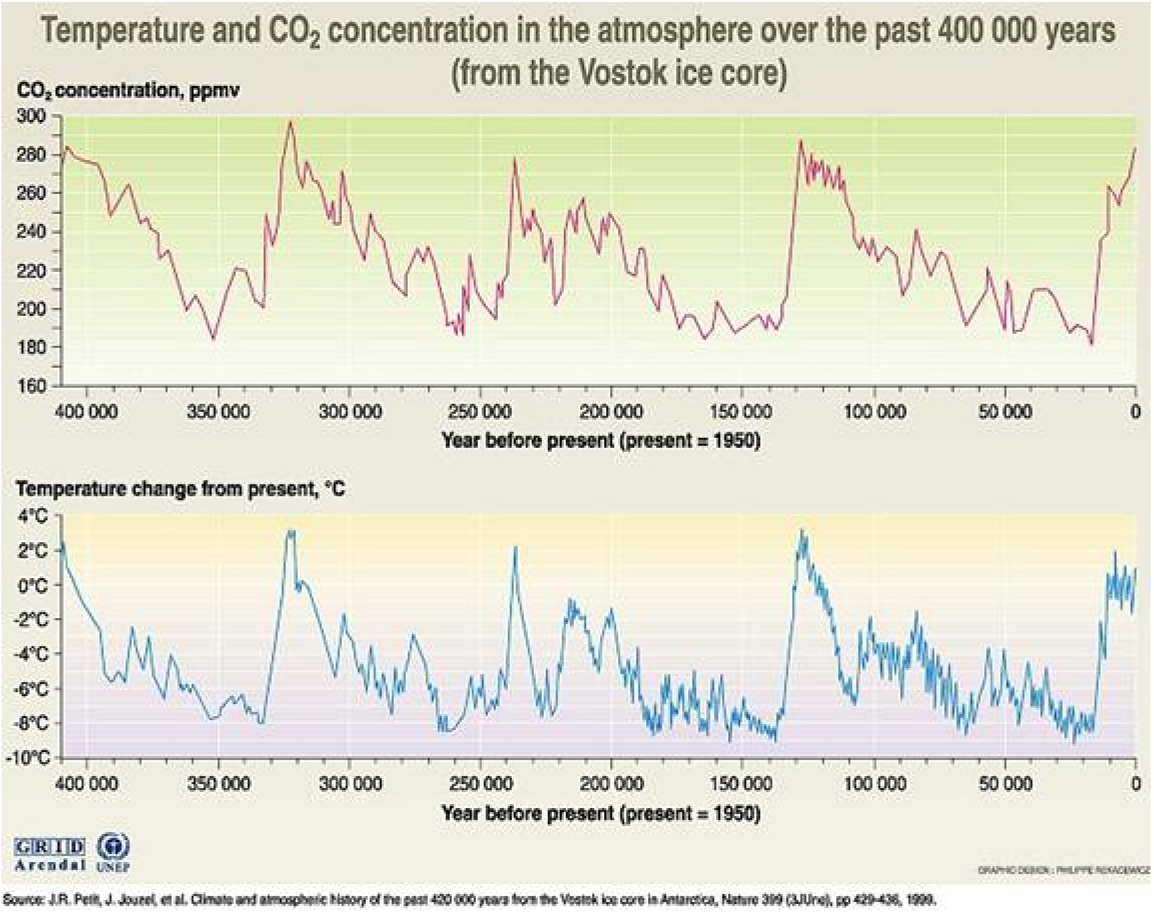

Figure 1http://www.grida.no/climate/vital/02.htm

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