Not So "Good Vibrations"
Molecules and Climate Change

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Rationale and Background:

This unit is appropriate for students in a second level biology course or an AP or IB biology course. The unit is based on previous knowledge that the students have on the topics of earth science including geochemical cycles such as the carbon cycle and water cycle. It also addresses student background knowledge of climate. Students should also have a background in general chemistry, especially covalent bonding and the electronegativity values for atoms. The students' biology background should include food webs, biomes and basic ecological principles. It is my goal to integrate these disciplines and to have students use their previous knowledge and apply it to an issue that is facing every living thing on the planet, namely global warming. It is my hope that the writing and communication skills the students use to complete lessons will expand their awareness of global climate change and its ramifications as well as encourage them to become informed stewards of our planet.

I teach at William A. Hough High School, a suburban high school that is located in Cornelius, North Carolina. The number of students attending the school is approximately 2000. We offer standard level, honors level, Career and Technical Education, and Advanced Placement courses that serve a variety of students. The school day is run on a block schedule where most classes meet for 90 minutes each day per semester.

As a biology teacher, I have spent my career teaching the methods of science. How scientists gather, analyze and share data is a focal point of my course. My students have spent countless hours working in the lab and writing lab reports. I have always stressed to them that the conclusions that they write must be based on the data that they gather. To me, data is what sets science apart from everything else; it is the only way of really knowing.

One of the main reasons that I developed this unit was because of an interaction between me and one of my former students. During a conversation I came to learn that he was a climate change "denier". I realize that when students are in high school they do not think for themselves very often and are reflecting the views of their parents. Nonetheless, I immediately logged on to the internet and found some of the latest published research about rising sea levels, melting glaciers, and rising carbon dioxide levels that all point to a rise in global temperatures. I handed them over to Zach, basically saying to him "*so there*" let's not discuss non-science in a science class. I had made the assumption that when an individual is presented with scientific data, they will immediately make what I thought would be an obvious conclusion that agrees with the point of view presented by the data. I also assumed that I had done a good job of proving my point to Zach and he could now be on board with the majority of the scientific community and agree that there was a significant anthropomorphic contribution to climate change. It was not until I read the article “The Psychology of Climate Change Communication” that I realized, much to my surprise, that the whole world did not know, trust or understand much about how data driven science is. The article pointed out to me that even though data tables and graphs make a powerful point to me, it is not the case for many individuals. It is extremely important to present information in such a way that the audience for which it is intended can understand it. The point should be made that to show a student a chart of rising sea levels really did nothing to educate Zach about climate change. Equally important, it did nothing to educate him, as was my goal, that there is an urgent need for humans to take action to reduce the negative impact that we make on our environment. The goals of this unit are not only to have students understand the importance of scientific work and use it as supportive evidence for their own knowledge, but to use scientific information to make a point that is easily understood by their peers. The subject of climate change, especially global warming and examples of the toll it is taking on living systems, will be the focus of their lessons.

This unit provides the teacher with information beyond the basic scope of an earth science class. I have provided background information regarding the energy balance that is necessary for a stable and livable earth environment, the chemistry of green house gases and their impact on climate change, the role of the carbon cycle, radiative forces that affect the Earth’s energy balance and information on anthropomorphic influences on global warming. I will also provide background information regarding ways that students can effectively communicate their knowledge to each other and those outside of the classroom. The activities are broad in scope and involve chemistry, communication and action. One activity is a chemistry based activity in which the students create molecular models of green house gases. Other activities involve research, writing and discussing the impact of global warming. The writing lesson is designed for students to research a topic that interests them and which can be directly linked to climate change. The methodology of the case study will be utilized for the writing activity. The students will use primary sources as a major component of their research. The idea is to guide them toward the results of scientific investigation and to have them rely on research data to tell the story of an organism or ecosystem that is affected by climate change. The teacher then facilitates a discussion that will help the students see the connections between their cases. This can be the beginning of further lessons on the topic of climate change. It is my goal that when the students present their cases to their classmates, a discussion will follow and it will lead them to conclude that they have written along a common thread: global warming.

Upon the completion of this unit students will:

1. Identify and explain the components of the Balance of Energy of the Earth System.
2. Describe the dipole moment of a molecule.
4. Explain what occurs at a molecular level during the absorption of infrared radiation by a molecule.
5. Create models of greenhouse gases that illustrate vibrational modes.
6. Understand the carbon cycle.
7. Understand the positive forcings of the greenhouse gases CO_2, H_2O and CH_4.
8. Write a case study based on the unit.
9. Present case studies and discuss the impact of climate change.
10. Participate in a discussion to brainstorm ways to affect positive change for our environment.

Teacher Background

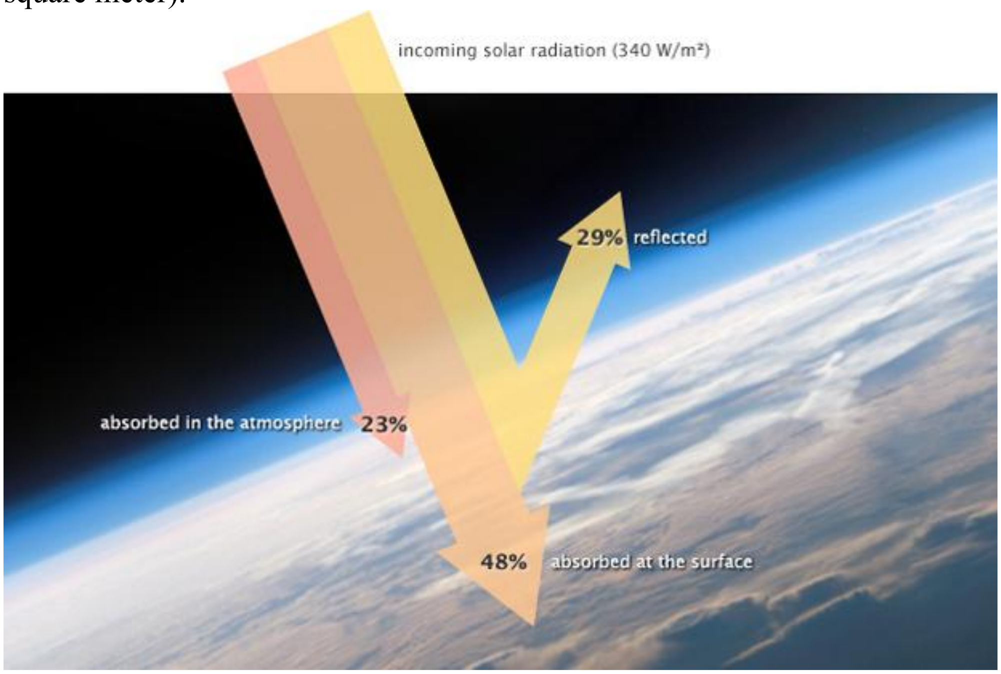
The main source of energy for the earth is the sun. This energy warms our planet, provides the energy for the water cycle and serves as the energy source for most of the organisms that exist. The sun is the major energy source for autotrophic organisms which utilize the chemical reaction of photosynthesis to synthesize organic molecules. These autotrophs serve as the base level of complex food webs that involve millions of organisms that live throughout the world.

In one year the Earth System, which includes land surfaces, oceans and the atmosphere, absorbs an average of 240 watts of solar power per square meter.[1] Since the earth is a sphere, the sun heats the equatorial regions more than the Polar Regions. The atmosphere and oceans must even out this solar imbalance and do so through several major processes: evaporation, convection, rainfall, and wind and ocean circulation. These same processes also redistribute solar heat from the Earth's surface and lower atmosphere back into space. If this did not happen the Earth System would steadily heat up. It is important to understand exactly how energy flows into and out of the Earth System. It is my goal to explain this balance as it existed before the industrial revolution, or in other words, before there was any significant contribution from activities by the human race. It serves to show the balance of energy before human impact on the environment.

The net flow of energy into and out of the Earth system is termed the Earth's energy budget. As with any budget, there must be balance. In this case the incoming solar energy must be balanced with an equal flow of heat to space; this is called radiative equilibrium. Equilibrium denotes a system where there is continued flow of energy or molecules. It is important to note that when equilibrium is reached the energy flow does not stop, but rather the net flow into or out of the system is zero.[2]

The following diagram (Figure1)[3] illustrates the distribution of solar radiation as it hits our atmosphere. It shows that 29 percent of solar radiation is reflected back into space by clouds, atmospheric particles (aerosols) and sea ice and snow. This energy has no impact since it is not absorbed by any molecules that make up the Earth System.

Next, we observe that 23 percent of the energy that passes into the Earth System is absorbed in the atmosphere by water vapor, dust and ozone. The last 48 percent passes through the atmosphere and is absorbed by the earth's surface. The earth's system includes the atmosphere and the surface thus 71 percent of solar energy is reaching the Earth System. As was stated earlier, this amount of solar energy is approximately 240 watts per square meter (71 percent of the total incoming solar radiation of 340 watts per square meter).



Source: Encyclopedia of Earth Figure 1

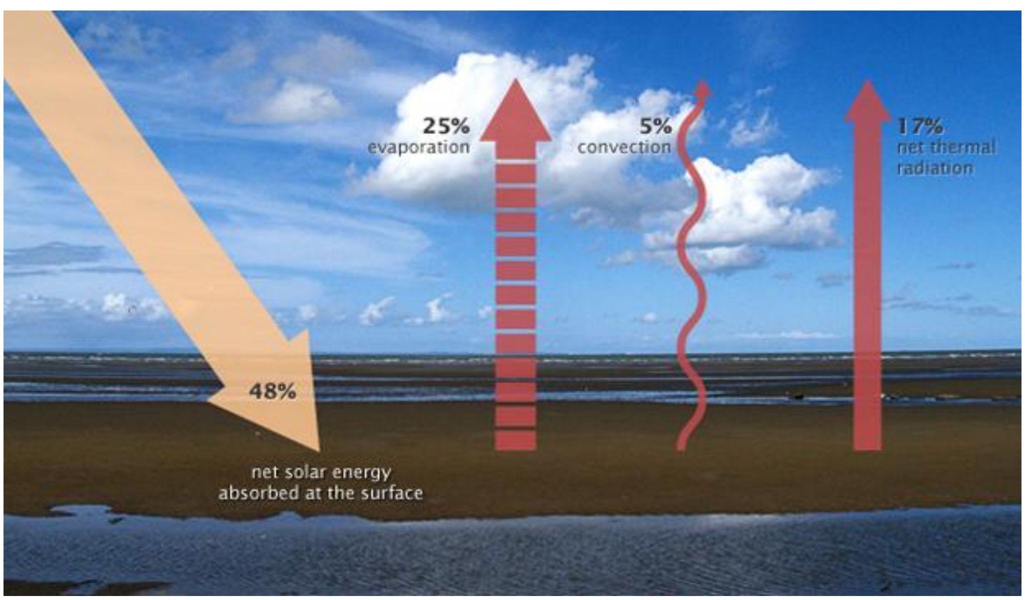
Prior to the industrial revolution the earth maintained radiative equilibrium. Approximately 240 watts per square meter of solar energy entered the Earth System and approximately 240 watts per square meter was measured as leaving.[4]

Following the path of solar energy in the Earth System

There are several things that happen to solar energy when it reaches our atmosphere. Some energy is reflected back into space before it reaches the earth's surface. Other forms of energy enter our atmosphere and may be reflected as visible light or absorbed. The energy that is absorbed both at the surface and by the atmosphere is the focus of this unit. When molecules absorb energy, they move more rapidly. This is what accounts for the temperature of a solid, liquid or gas. Thus this explains how matter on the earth and in our atmosphere can increase in temperature. Luckily the atoms and molecules on earth do not just absorb energy; they also release it as infrared radiation. Infrared radiation (IR) is also known as heat. In a pre industrial Earth System there is a balanced energy budget. The amount of heat that is radiated back out to space is enough to balance the increase in temperature caused by the solar energy reaching the Earth system. An explanation of this energy balance can be divided into two parts. Part one is what happens to the energy that is absorbed by earth's surface; part two is what happens to the energy that is absorbed by the molecules and atoms in the atmosphere.

Energy balance of the Earth's surface

In order to understand how this energy balance affects living systems on the Earth's surface we need to consider what is occurring with the 71 percent of the solar energy that reaches the Earth System. Of this 71 percent, 48 percent is reaching the earth's surface and is absorbed by the land and water that make up the Earths surface. In order to balance the "energy budget", the earth must now dispose of 48 percent of the energy that reaches its surface. There are three ways that the Earth system accomplishes this: evaporation, convection and the emission of thermal infrared energy (the releasing of energy into space that is trapped in atoms and molecules). The following diagram illustrates this principle (Figure 2)[5]:



Source: Encyclopedia of Earth

Figure 2

Each of the values represented by the arrows is explained as follows:

Evaporation (25 percent cooling effect) is when liquid water absorbs enough energy to change into the gaseous phase. Because of the hydrogen bonding between water molecules, the molar enthalpy of vaporization is 41 kJ/mol which is considered very high.[6] When the water molecules absorb energy they move faster and can break the hydrogen bonds that keep them in the liquid state thus changing into the gaseous phase. The energy that is required for this phase change essentially serves to cool the earth's surface since the water molecules take the energy with them and spread it through out the atmosphere. (In a biological context, this is why sweating works to cool a human). When the water molecules condense into rain, this heat is released into the surrounding atmosphere and serves as source of atmospheric heating. This is one way that water vapor serves as a greenhouse gas.

Convection (5 percent cooling effect) works using the principle that warm air rises and cool air sinks. Because the surface of the earth absorbs solar radiation and reemits it as heat (infrared radiation), air is warmer near the surface of the earth. This warm air rises while air that is farther from the earth sinks. These currents serve to cool the surface of the earth.

Thermal infrared radiation (approximately 17 percent cooling) is the heat radiated by atoms and molecules on the earth's surface. Approximately 12 percent of this heat rises to the upper levels of the atmosphere and eventually rises to a point where it does not affect the temperature of the Earth System and is essentially dissipated into space. That leaves approximately 5 to 6 percent of infrared energy trapped in the atmosphere (Keep in mind- 5 to 6 percent).

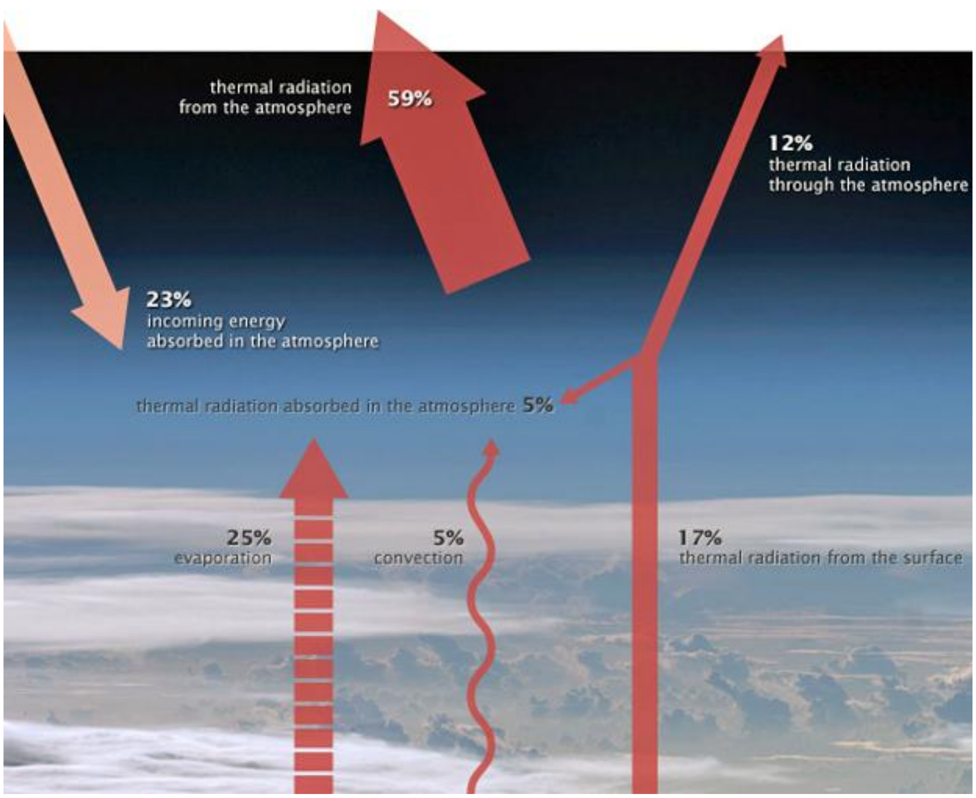
Energy balance of the Atmosphere

Satellite measurements have shown that 59 percent of incoming solar energy is radiated out as thermal infrared radiation.[7] Since the amount of radiation leaving the Earth System must balance, that means that there must be the same amount being absorbed. Since it was previously mentioned that some of the surface heat is lost via evaporation and convection, 25 percent and 5 percent respectively, and since these occur in the atmosphere, their contribution to the energy balance can be considered here as well. There is a significant amount of energy that is absorbed in the atmosphere by clouds, aerosols, water vapor and ozone. This amounts to a total of approximately 23 percent.

If one were to add the percentages of energy absorbed by these atmospheric components, there would be a total of approximately 53 percent of incoming solar radiation accounted for. Since we must balance the 59 percent that is radiated out, we have a left over amount of energy of about 6 percent.

This amount of 6 percent has been previously mentioned in the last section as being "trapped in the atmosphere" in the accounting of the surface energy balance; it is also the same 5 to 6 percent that makes up the difference in the energy balance of the atmosphere. This is a crucial 5 to 6 percent since this is the amount of energy that is absorbed by the "major" greenhouse gases of water vapor, methane and carbon dioxide. This heat energy is trapped in the molecules or scattered into our atmosphere before it can escape into space. Pre- industrial concentrations of these atmospheric gases have not been considered as influencing the energy balance of the earth. Paleoclimate data such as records of climate that are preserved in tree rings, skeletons of coral reefs, glaciers, ice caps and buried in sediments of oceans and lakes all point to the fact that significant warming of the atmosphere has occurred since the 19th century.[8]

The diagram below illustrates the energy balance of the atmosphere (Figure3).



Source: Encyclopedia of Earth Figure 3

The Chemistry of Greenhouse Gases

Greenhouse gases have been given a bad reputation yet these are the gases that make our planet livable. The gases of carbon dioxide CO_2, water H_2O and methane CH_4 are the primary greenhouse gases.

As was mentioned earlier, the sun is the source of many types of electromagnetic energy that reaches the earth. The high energy, short wavelengths such as visible light pass through the atmosphere and are absorbed. The energy that is absorbed by the earth is reradiated as longer wavelengths of infrared energy some of which cannot pass back out into space. Infrared energy is also known as heat, thus this trapped energy is the cause of the warming of our atmosphere. The green house gases are the main sources of such absorption. In order to understand how these gases accomplish this, it is necessary to look at their molecular structure. The greenhouse gases are compounds of different types of atoms bonded together by covalent bonds. Covalent bonds result from the sharing of electrons between two or more atoms in the molecule. The nature of this bond is influenced by, among other things, the electronegativity of the atoms in the molecule. Electronegativity is an atom's tendency to attract the electrons that are being shared in a covalent bond. In the molecules of CO_2, H_2O and CH_4 there is a difference in the electronegativity between the atoms.

In CO_2, oxygen is more electronegative than carbon. Therefore in the covalent bonds that join the oxygen atoms to the carbon atoms, the electrons are spending more time around the oxygen nuclei. As this happens, it creates an imbalance of electrons causing the bond to become polar. This is known as a permanent dipole moment. That is, one end of the bond, the oxygen end, maintains a negative charge, while the carbon atom maintains a positive charge. In the case of H_2O, it is the oxygen atom/hydrogen atom bond that is polar with oxygen being negative and hydrogen being positive. The CH_4 molecule has polar bonds between the central carbon and four hydrogen atoms, with the carbon center of the molecule maintaining a negative charge while the hydrogen ends have a positive charge. Below are the structural formulas of each molecule indicating their polarity:[9]

The carbon dioxide molecule: Note the direction of the dipole and the linear geometry. This illustration (Figure 4) also shows that the bonds between the carbon atom and the oxygen atoms are double bonds. That is, there are two pairs of electrons that are shared within each bond.

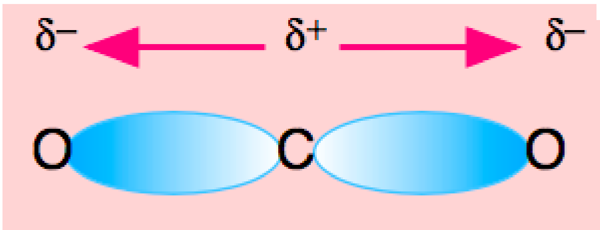


Figure 4

The water molecule. Positve and negative sides of the molecule are noted. The geometry of the water molecule is bent with the bond angle at 107 degrees. The covalent bonds of the water molecule are single bonds where one pair of electrons is shared (Figure 5).

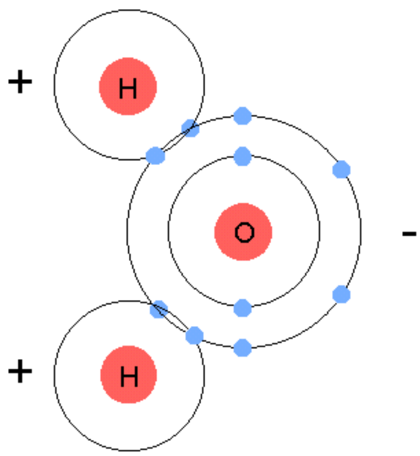


Figure 5

The methane molecule: The arrows indicate the direction of the positive charge. The geometry of the methane molecule is tetrahedral (Figure 6).

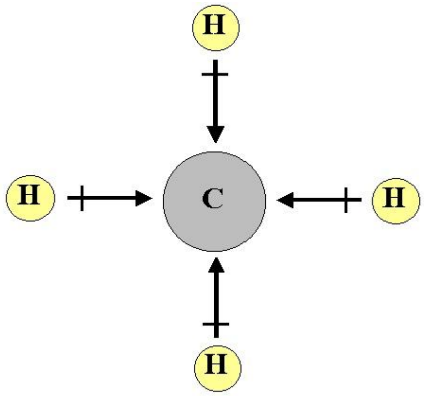


Figure 6

Polarity and Vibrational modes.

In the carbon dioxide molecule, two oxygen atoms are bonded to a central carbon atom. These bonds are double bonds in which two pairs of electrons are shared. The carbon atom and the oxygen atom differ in electronegativity which results in a dipole moment. The dipole moment of the CO_2 molecule allows for the absorption of infrared energy (IR). As the molecule absorbs energy, the dipole moment changes resulting in what is termed a vibrational mode. A vibrational mode can be described as bending or a symmetric stretching of the bonds. When molecules stretch, the bond lengths become longer then shorter. When they bend, the length of the bonds stays constant, but the angle between them increases or decreases. A molecule can *only* absorb infrared energy and thus have vibrational modes if absorption of this energy results in a change in the dipole moment.[10] Not only does the molecule absorb this energy but it also emits it in every direction thereby heating the atmosphere surrounding it.

The vibrational modes of Carbon Dioxide

Carbon Dioxide is a linear molecule and has four different vibrational modes. The oxygen atoms can stretch either symmetrically or asymmetrically from the carbon atom; or the molecule can bend in a vertical or horizontal orientation. There is a link provided in the teacher's resource section that provides a video clip of these vibrations. Only two of them are considered to be IR active and are shown in Figure 7.[11] Also included in the diagram is the IR spectrum of carbon dioxide as measured by an infrared spectrometer. The infrared spectrometer is a device that can detect the frequency of radiation that is absorbed by a sample. The dips in the lines represent absorption in the IR region which extends from approximately 600 cm^{-1} to 4000 cm^{-1}. The units used in this case refer to the number of waves per centimeter.

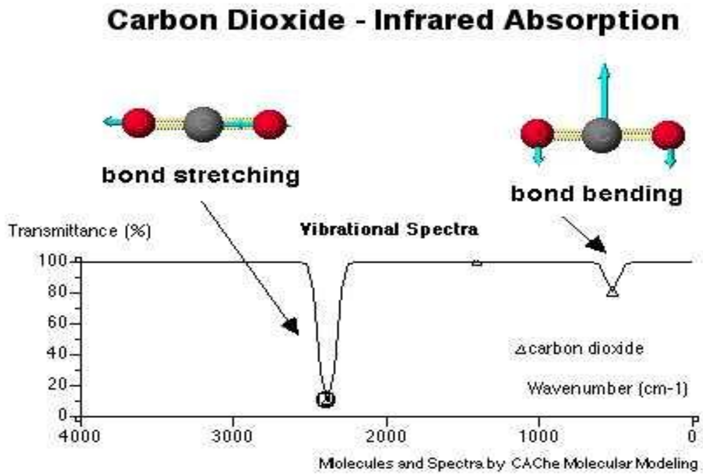


Figure 7

The Vibrational Modes of the Water Molecule

The vibrations of the water molecule also allow for the absorption and release of heat. The water molecule is bent, not linear and has three vibrational modes. The hydrogen atoms can stretch either symmetrically or asymmetrically from the oxygen atom; or, the molecule can bend in a symmetrical manner such that both hydrogens are either bent up or down. The modes and the IR spectrum for the water molecule are shown in Figure 8. [12] The teachers resource section has a link to a video clip showing these vibrations.

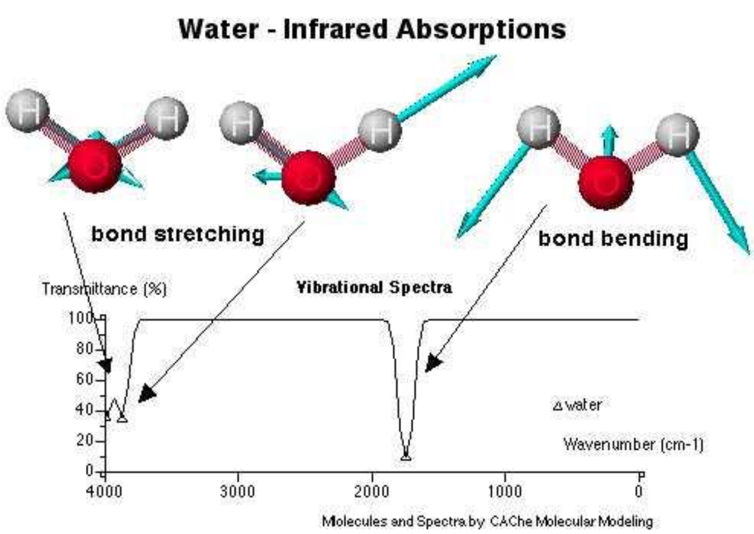


Figure 8

The Vibrational Modes of the Methane Molecule

The methane molecule is tetrahedral in shape and all of the carbon hydrogen bonds are single bonds. There are nine possible vibrational modes since there are so many combinations of bending and stretching movements. Of these nine possibilities only two of them are considered to be infrared active (Figure 9).[13] These two modes are those in which both the carbon and the hydrogen atoms move. The teacher's resource section has a link to a video clip showing these vibrations. Since methane has single bonds, compared to the double bonds of the carbon dioxide molecule, it is easier for the methane molecule to vibrate. Thus, the amount of energy absorbed and emitted by methane is greater than the energy absorbed and emitted by carbon dioxide. The IR spectrum is also included.

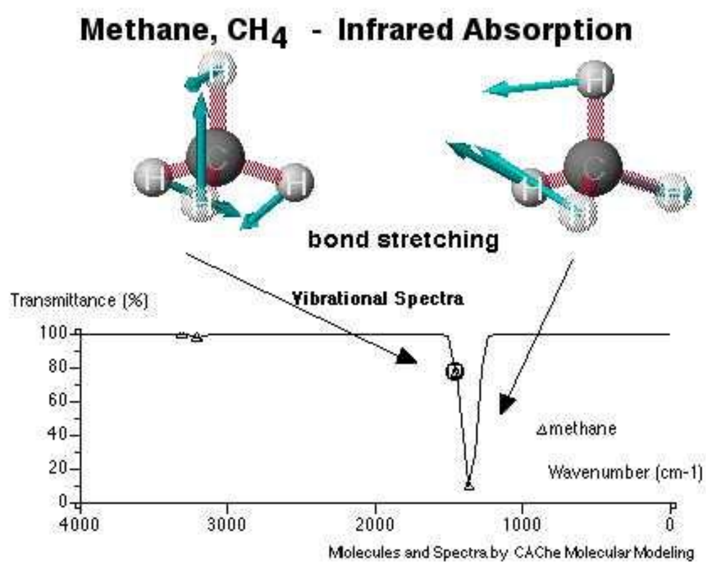
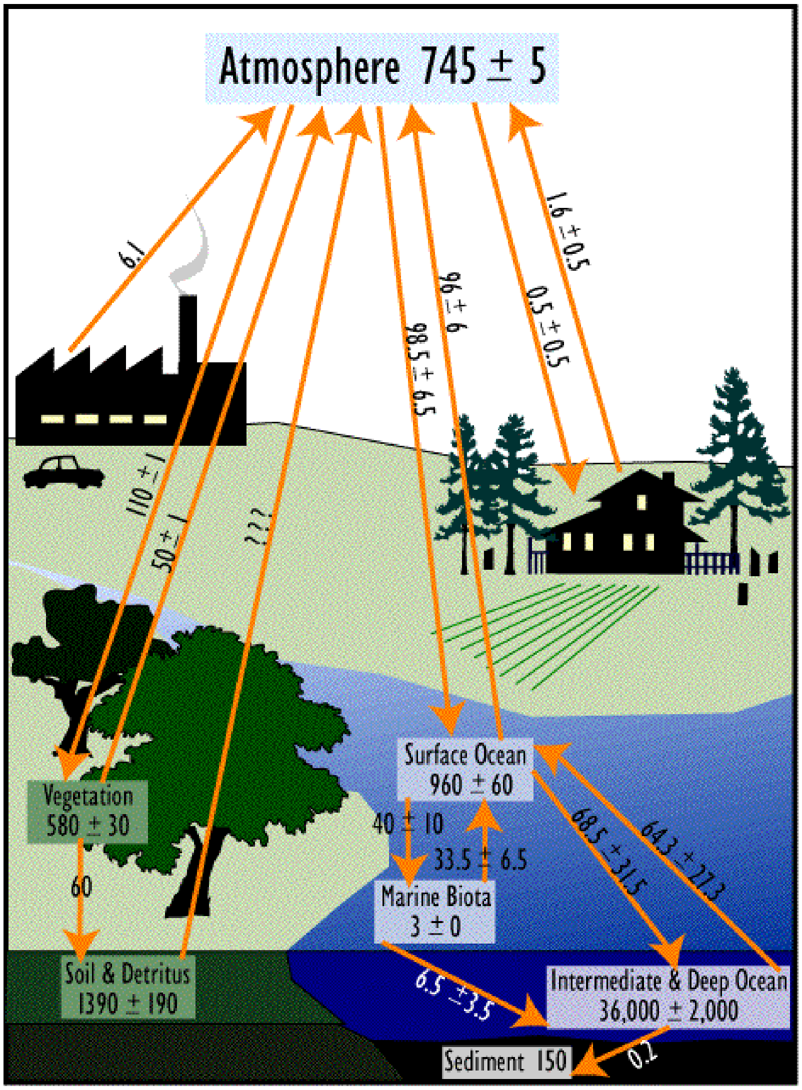


Figure 9

The carbon cycle and its relationship to climate change

Although the ability of the carbon dioxide molecule to absorb and emit IR radiation is trumped by the methane molecule, it is currently the gas that has the most influence as a greenhouse gas. This is primarily due to its high concentration in the atmosphere. The carbon atom can be traced through the carbon cycle. The concentration of carbon dioxide in the atmosphere is dependent on a number of factors. There are events that place carbon dioxide into the atmosphere, events that remove it from the atmosphere, and events that trap the carbon dioxide for extended periods of time. The carbon cycle is typically taught to students in early grades. It shows how carbon dioxide enters the atmosphere primarily through respiration and combustion of fossil fuels. It also illustrates how carbon dioxide is removed mainly through photosynthesis on land and in the oceans and it shows how carbon dioxide is trapped in the carbon of fossil fuels yet to be “harvested”. If one looks at the geologic history of the earth, this cycle takes millions of years to move large amounts of carbon dioxide from one system to another.[14] This point is often lost on students and should be part of the lesson.

The carbon cycle is illustrated in Figure 10.[15] The sinks of carbon are represented by the boxes while the arrows represent ways in which these sinks exchange carbon. The amounts of carbon are measured in gigtons (Gt C) for example, plants absorb 110 (+/- 1) Gt C during photosynthesis and release 50 (+/- 1) Gt C during respiration. Another important point of exchange is between the atmosphere and the ocean. Carbon dioxide is dissolved in the ocean and used by marine autotrophs for photosynthesis. It should be noted that the ocean absorbs 2.5 Gt C more carbon from the atmosphere than it gives off. This would seem that the ocean sink is therefore growing, which would be a good thing. However the burning of coal, oil, natural gas and gasoline adds 6.1 Gt C to the atmosphere (represented in the diagram by the factory and the car). These processes do not provide a way to cycle carbon thus they continually add it to the atmosphere. In fact, carbon dioxide levels in the atmosphere have increased by 30% since the Industrial Revolution[16]. Another exchange that should be noted is that of land use (this is represented by the house and trees). This includes human activities such as agriculture, deforestation and reforestation. Each of these processes has an impact on the others giving us a very complex system.



Source: NOAA carbon cycle Figure 10

There has been a drastic increase in the amount of carbon dioxide added to the atmosphere since the Industrial Revolution which has caused the cycle to become lopsided. The cycling of carbon now must occur in centuries or decades, rather than millions of years in order to maintain the balance of carbon between organisms and the abiotic factors of the Earth System.

The Scripps Institution of Oceanography and NOAA Earth System Research Laboratory are continually monitoring carbon dioxide levels at the Mauna Loa Observatory (Figure 11).[16] Information for current data can be found in the teacher resource section of this unit.

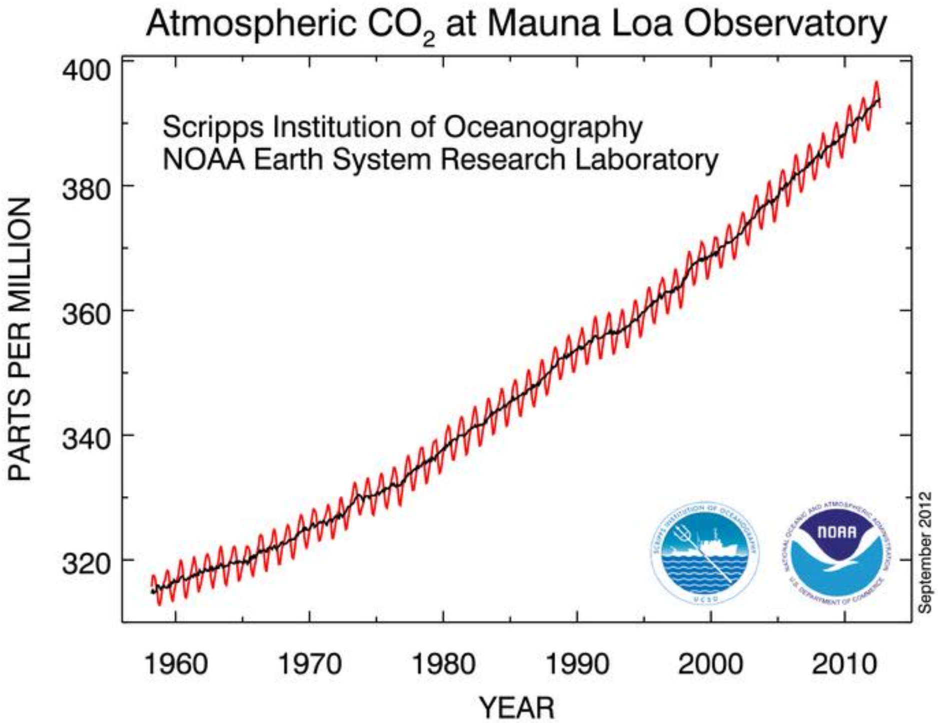


Figure 11

As was stated earlier, the energy balance of the earth must be maintained to achieve stable global temperatures. The variable in this balance has been pointed out to be greenhouse gases (the 5-6 percent) that absorb infrared radiation from the earth. Any change that disrupts this balance is called a forcing agent. Positive forcing increases the temperature of the Earth System while negative forcing reduces the temperature of the atmosphere.

Much research has been done to account for these forces and is summarized in Figure 12.[17] It is important to note that the anthropomorphic additions of carbon dioxide account for a significant degree of positive forces. Other GHGs stands for "greenhouse gases".

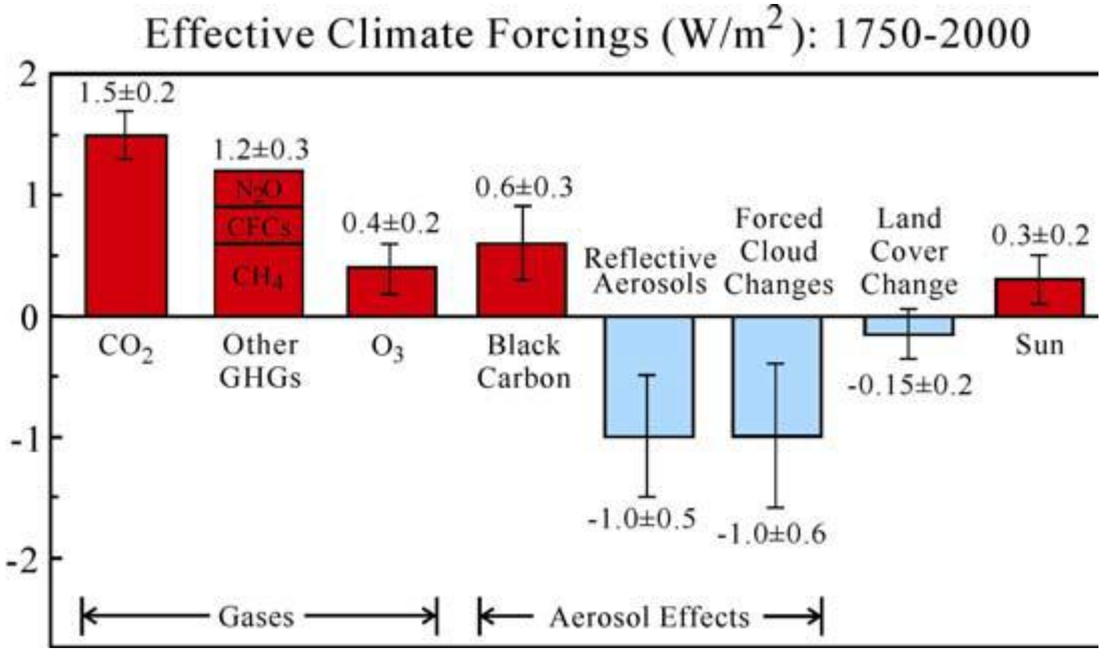


Figure 12

Climate forcing agents in the industrial era.
"Effective" forcing accounts for "efficacy" of forcing mechanisms.
Source: Hansen

The level of carbon dioxide gas is considered a significant positive forcing. The conclusion can be made that rising global temperatures (Figure 13)[18] are mainly the result of anthropomorphic contributions of carbon dioxide and other greenhouse gases to the atmosphere. The rising level of carbon dioxide is a major threat to our environment because of its effect on global warming. Other greenhouse gases such as methane have the potential to cause an even larger positive forcing. If current levels of methane in the atmosphere increase, its effect on global warming will be significant. This is due to the fact that each methane molecule, with its single carbon/hydrogen bonds, easily absorbs and emits infrared radiation.

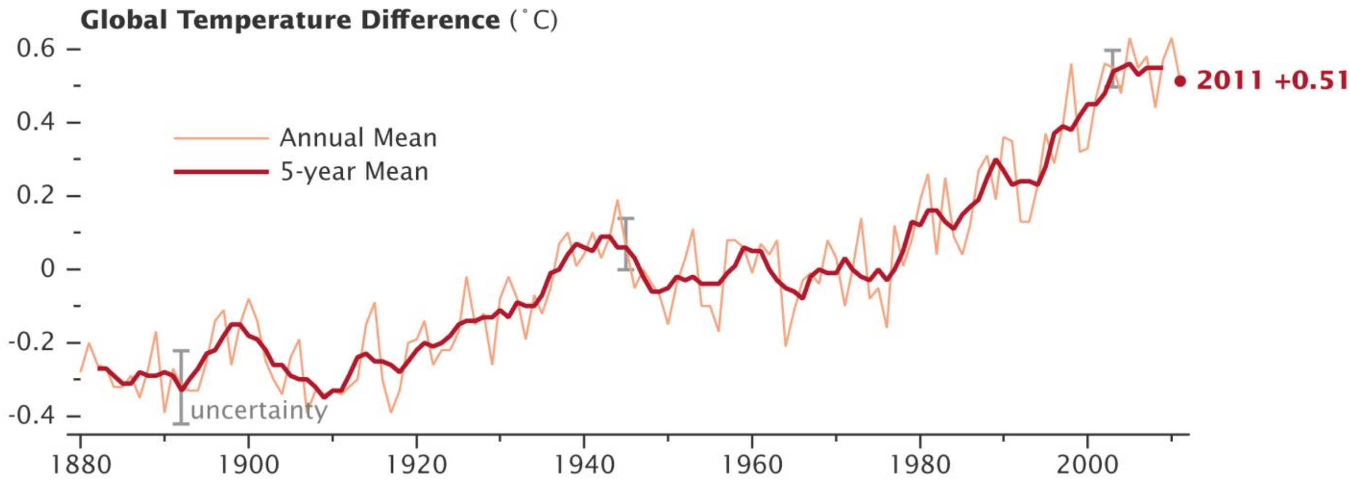


Figure 13

(Data source: NASA Goddard Institute for Space Studies. Image credit: NASA Earth Observatory, Robert Simmon)

If students are given a good background in the fragile energy balance of the earth, the chemistry of the greenhouse gases, the carbon cycle and carbon dioxide as a positive forcing, they will be able to participate in lessons that not only increase their own knowledge, but enable them to communicate these concepts to others.

Successful communication by the teacher and amongst the students can help achieve the goals of this unit. Research done by the Center for Research on Environmental Decisions shows that in order for information on climate science to be absorbed by an audience it must be "actively communicated with appropriate language, metaphor, and analogy: combined with narrative storytelling; made vivid through visual imagery and experiential scenarios; balanced with scientific information; and delivered by trusted messengers in a group setting." [19] Since the group setting is the classroom, I have chosen the case study method as the primary tool to teach this unit. A case study method uses cases which are real world examples or stories to illustrate a concept. Cases can be data based examples of scientific phenomena or narratives that are based on evidence. The key to a case is that it must present information in a way that engages the reader. Included in the unit are lessons using case studies. The first lesson is one in which the teacher presents several cases to students. I have provided a source in the teacher resource section that contains many case studies to choose from that are all linked to climate change. Students are given cases either individually or in small groups and are asked to read then analyze their case. A class discussion follows that allows students to make connections between the cases and global warming. The teacher directed case studies are very data oriented and serve as good examples of using data to support the case. This lesson is followed by an assignment for students to write their own case study. Case studies allow the students to be active participants in their own learning. Students must use critical thinking skills and apply previously known information to a new concept. As they study cases and write their own they learn effective methods of communicating vital information about a serious environmental issue.

Activities for Students

Activity 1: Teacher Guided Case Study Analysis

An excellent resource for teachers to find case studies for students is http://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4-wg2-xccc.pdf.
Teachers can print off cases that seem interesting and ask the students to read them.

As students are reading the cases they should do the following:
***evaluate the credibility of the information;
***determine whether the evidence provided is relevant to the particular case;
*** determine the major issues of the case;
*** write discussion questions regarding their case.

When students have completed their assignments, the teacher can lead a discussion where each student addresses the above statements. The teacher can then lead the students to the conclusion that all of these cases are the result of human induced climate change. Students can also be encouraged to predict what may happen in their particular case if our climate continues to warm. They can also discuss possible plans for remediation of these cases.

Some possible discussion questions that are based on the IPCC articles are as follows:

Article C4, Indigenous Knowledge for Adaption to Climate Change:
***Is indigenous knowledge more important than scientific knowledge?
***Why does adaptation constitute a priority problem at the local level?

Article C2.1 Present Day Changes in Coral Reefs:
***Why does one hurricane, with a stronger intensity cause more damage than several repeat hurricanes, with a lower intensity?
***Based on our knowledge of what impacts coral reefs, what steps can we take now that will lessen the threat of deterioration?
***Which concern impacts coral reefs the most, increased acidity, storm intensity or sea surface temperatures? Could it be the combination of the three that is needed to destroy coral reefs?
***What are some long term effects of reef damage?
***Which will be affected more, human or marine populations?

Article C.1 The Impact of the European 2003 Heat Wave.

***How did the heat wave of 2003 produce a challenging living environment for aquatic animals?
***How would have the increase in temperature affected agriculture if it had not been accompanied by a drought?
***How did the heat wave of 2003 effect Europe economically?
***What will happen if large amounts of carbon are lost in biospheric stocks?
***Why does a drought increase air pollutants?
***Is the heat wave a cause or the result of unmanageable environmental change?

Activity Two: Student Generated Case Studies

Students will create a case study that will focus on a particular organism or population of organisms that have been affected by climate change. This will be a narrative that is heavily supported by data. Students are to create the case by incorporating data from primary sources to support and explain the situation of the case. It is my goal that they use a case study to effectively communicate an environmental consequence of global warming. In general, the narrative will be such that there is a protagonist that finds itself in a situation caused by global warming. The narrative should have a beginning, middle and an end such that the reader can learn about the particular organism and its life story. Events should include those before global warming, current challenges and the outlook for the future based on current models for climate change.

The Case Study Guidlelines:

---A connection between the case and global warming must be evident.
---The case must be heavily supported by data and the data must be properly cited.
---The story of the case must be engaging so that the reader can empathize with the protagonist or situation of the case.
---The case should include three or more discussion questions.
---Standards of English, grammar and punctuation must be followed

There are many possible topics for case studies that can be linked to global warming. Some topics that students may explore are as follows: migration patterns, respiratory disease, diseases with insect vectors, polar bear population study, amphibian decline, extinction of species (biodiversity studies), Emperor or Adelie penguins, Coral or Caribou.

An example of a case study involving the decrease in a polar bear population may involve the story of a polar bear as she struggles to hunt seals in order to feed her cubs. It may include a narrative that may have the polar bear "remembering stories of easy hunting" that were told to her by her grandmother or great grandmother. The narrative is supported by data that show the thinning of the arctic ice. It should be supported with actual data of declining numbers of polar bears in a specific habitat or location. The change in habitat, the loss of food and the near starvation or starvation that follows must be linked to climate change.

Activity 3. Presentation of the Case.

Create a presentation in the form of poster or Power Point Presentation. The poster or PPT should have pictures of the organism of the case and data (tables, graphs) that are used to support the narrative. The student that presents the case must be able to explain the cause and effect relationship between global warming and their specific case. Other students in the class may be required to ask questions based on what they know from their own case studies. A class discussion can be based on the questions provided by the author of the case or by discussion questions that are generated during the presentation of the case.

Activity 4. Using the Case as a Teaching Tool.

Students can be invited to present their cases to the PTA, local officials or the staff at school. Another option would be to create a children's book which will translate the case into easier language that is understood by an elementary age student.

Activity 5: Student Generated Models of Greenhouse Gases

Using materials from home, students are to construct molecular models of water, carbon dioxide and methane. Any safe building, craft or food materials may be used in making the models. Each model must be able to show the IR active vibrational modes. The students will have to research videos on line that show the vibration modes and be able to demonstrate them using their models. The students must include in their demonstration an explanation of the relationship between vibrational modes and heating of the atmosphere. They should also include the current level of each gas in the atmosphere.

These demonstrations can be in small groups that are monitored by the teacher. The teacher may select students to visit other classrooms that may be studying climate change and use their models to explain how greenhouse gases work

Included in the teacher resources are links to web sites that have videos of molecular vibration. Absorption spectrum data is also interesting for these molecules and can be included in the lesson.

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Activity 6: Student Plan of Action.

Students will conduct research and present solutions that are currently being pursued to reduce carbon dioxide emissions. These can be presented in a discussion format and then a poster.

Students can research ways of improving carbon dioxide sinks. This would accomplish the goal of reducing the amount of CO_2 in the atmosphere, in addition to reducing carbon dioxide emissions from burning fossil fuels.

Grassroots organizations such as 350.org can also be explored as a group activity so that students feel empowered to change public thinking and governmental policy on climate change.

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