GLOBE (Global Learning and Observations to Benefit the Environment) is a worldwide hands-on, primary and secondary school-based science and education program. GLOBE's vision promotes and supports students, teachers and scientists to collaborate on inquiry-based investigations of the environment and the Earth system working in close partnership with NASA and NSF Earth System Science Projects (ESSPs) in study and research about the dynamics of Earth's environment.

Announced in 1994, GLOBE began operations on Earth Day 1995. Today, the international GLOBE network has grown to include representatives from 110 participating countries and approximately 140 U.S. Partners coordinating GLOBE activities that are integrated into their local and regional communities. Due to their efforts, there are more than 45,000 GLOBE-trained teachers representing over 20,000 schools around the world. GLOBE students have contributed more than 18 million measurements to the GLOBE database for use in their inquiry-based science projects.

GLOBE brings together students, teachers and scientists through the GLOBE Schools Network in support of student learning and research. Parents and other community members often work with teachers to help students obtain data on days when schools are not open.

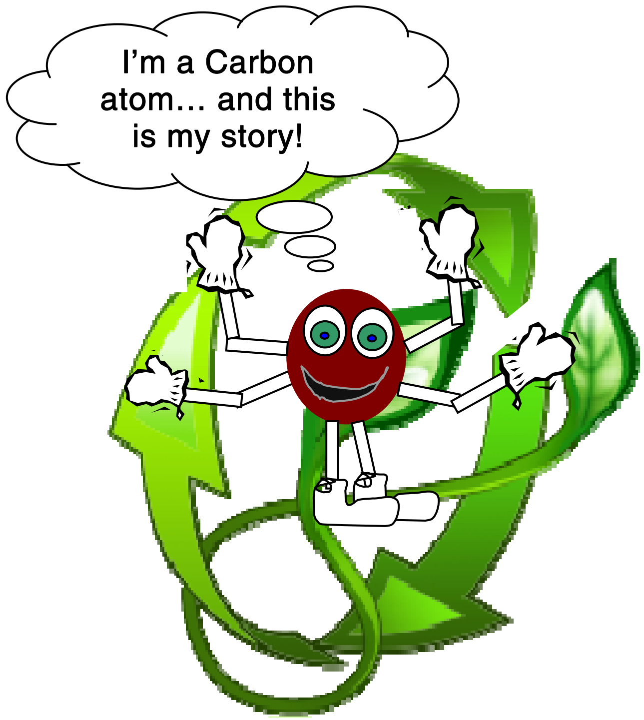
www.globe.gov

DRAFT – 10_10_08

Can you…

Follow the Carbon Atom?

A self-guided adventure through the Carbon Cycle



The GLOBE Program

DRAFT – 10_10_08

Glossary of Terms

Atom – The smallest particle of an element. An atom can not be divided by chemical means.

Cellulose – A carbohydrate (an organic compound, produced by living things; including sugars, starches, and cellulose, which is a major energy source of animals.) made up of glucose molecules forming the main part of the cell wall in most plants.

Decomposition – The process of something decaying or rotting, breaking down into its basic elements.

Hydrocarbons – Molecules made up of long chains of carbon atoms with hydrogen atoms attached on both sides

Internal combustion engine – An engine, such as an automobile engine, that burns fuel inside the engine.

Microorganism – An organism too small to see without some magnification.

Photosynthesis – The way that green plants and some other organisms make their own food from carbon dioxide and water using sunlight. Oxygen is released.

Phytoplankton – Very small aquatic plants, many are too small to see without some magnification.

Respiration – The reverse of photosynthesis in that oxygen is taken in to use stored carbohydrates as energy. Carbon dioxide and water are produced.

Sediment – Material that settles to the bottom of a liquid (e.g. rocks falling to the bottom of the sea).

Plant senescence – The process of a plant saving valuable resources (glucose, water, etc) during the cold or dry season by cutting off nutrients to leaves. Leaves ususally turn colors (reds, yellows, etc) during plant senescence.

Terrestrial – Living or growing on land.

Thermohaline current – The movement of deep water in the oceans driven by differences in density (density equals mass divided by volume) caused by salinity and temperature (e.g. the more saline the water the more dense, the colder the water the more dense).

Hello again! So, we've followed the leaf to the forest floor. The carbon atom that we're following had been absorbed by the leaf and, along with some water (H_2O) and sunlight, been converted to glucose. The glucose then became part of the cellulose of the leaf. Now many leaves of different colors cover the ground. They've fallen from the trees around us.

Now the carbon atom will need to move someplace else. But the leaf laying on the ground makes it is easy for carbon to get moved to many different places! The leaf might be eaten by small animals *decomposed* by *microorganisms*, or slowly buried beneath more and more layers of plant litter (leaves and trigs). A fire could even come through and send it quickly back to the atmosphere.

1) Become buried in soil (Go to page 19)

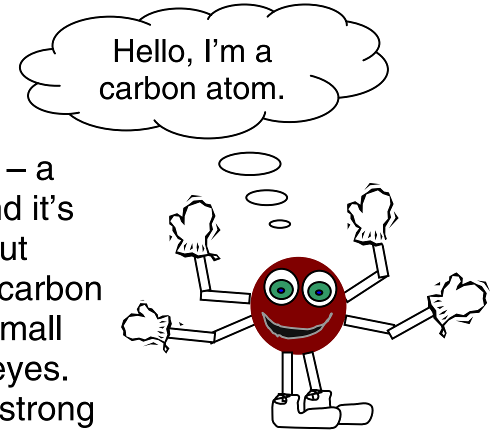
2) Return to the atmosphere as CO_2 during *respiration* by microorganisms (Go to page 4)

3) Be eaten by a beetle (Go to page 11)

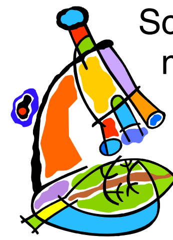
4) Fire burns the leaf; return to the atmosphere as carbon dioxide (Go to page 4)

Can You…
Follow the Carbon Atom!

What is carbon?



Carbon (C) is an atom – a chemical element – and it's almost everywhere! But you can't actually see carbon atoms – they are too small for us to see with our eyes.

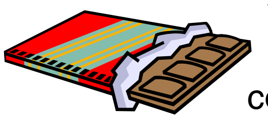


Scientists use strong microscopes to see very small things but even strong microscopes can't see single atoms.

Many scientists call carbon the building block of life. Most of you have probably used building blocks, like Lego's®, when you were younger. Almost like how building blocks can connect together to build things, carbon and other elements connect together to build things too. Chemical elements connect together into "molecules" or "compounds" – groups of atoms stuck together. These molecules then help to build things like trees or animals – even you and me! Wow! Pretty cool, huh?

Carbon is one of the most abundant elements in all living things and the 4th most abundant element in the universe.

Carbon can also be found in Earth's atmosphere (the air we breathe), the soil that we walk on, in the oceans, and in the Earth's surface (like rocks). So what kind of molecules does carbon make? Here are some examples of how carbon connects with other very popular atoms like hydrogen (H), oxygen (O), and nitrogen (N). If one carbon atom joined up with two oxygen atoms it would become carbon dioxide (CO_2); if six carbon atoms joined up with six water molecules (H_2O) it would become a simple sugar called glucose ($C_6H_{12}O_6$); and if eight carbon atoms joined up with ten hydrogen, four nitrogen and two oxygen atoms it would become caffeine ($C_8H_{10}N_4O_2$). Caffeine is found in chocolate, sodas, coffee, and many teas (I wonder if your parents know that carbon is in caffeine?).



We could go on forever describing many more compounds but maybe we should get back to our story.

When carbon joins with these other elements to form molecules they can be in the form of a solid, a liquid or a gas. And with some energy, carbon can change forms, or even move from one molecule to another to form a new compound. Movement from carbon in trees to carbon in the air to carbon in the oceans and on and on is part of the carbon cycle.

You are about to take a journey through the global carbon cycle following a carbon atom. Each time you travel to a new place you will learn about how carbon plays a role there. You will then have options about where carbon should travel next. As

The carbon has now entered the ***terrestrial*** food web. As it moves from plant to animal to animal the form may change – it might combine with water molecules (H_2O) to form the simple sugar called glucose ($C_6H_{12}O_6$) or leave any of the animals along the food web as carbon dioxide (CO_2) through ***respiration***.

It is very exciting to move with carbon from organism to organism! Every plant and animal within the food web is made up of molecules containing carbon – from tiny bacteria to the lion and everywhere in between. I think I'm beginning to understand why carbon is called the "Building Block of Life." We have followed the carbon atom as it moved along the food web all the way to the lion. It could have taken many different paths to reach this point.

1) Leave the food web as carbon dioxide (CO_2) during respiration (Go to page 4)

2) Leave the food web as methane (CH_4) when waste is produced (Go to page 12)

3) Stay in the lion until it dies (Go to page 22)

Death isn't a pleasant topic, but the death of an animal or plant is a natural part of the Earth system. Yoda said it best in Star Wars: "Death is a natural part of life." While Yoda and Star Wars films are fictional, this comment is true. Carbon atoms move from one state of matter to another as a natural part of the Earth system.


Source: www.disneyclips.com

As the animal ***decomposes*** the carbon becomes buried in soil. Thousands of ***microorganisms***, or microbes, in the soil help decompose animals, like those that decompose plants. This makes more nutrients, like nitrogen, available to plants. The carbon however is respired by the microbes so the carbon atom may move back into the atmosphere.

While much of the decaying animals are eaten by microbes, dead plants and animals still die and build up. This build up forces some of the partially decomposed material to move down in the soil layers. Because there isn't as much oxygen down here decomposition happens more slowly if at all. As the un-decomposed matter gets buried quickly by a landslide or slowly by tree litter the carbon becomes locked away for hundreds to a thousand years.

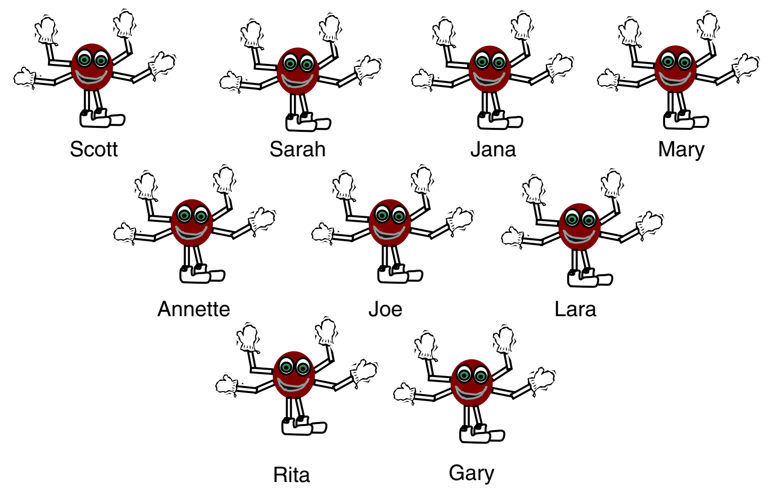
1) Move back into the atmosphere as carbon dioxide (CO_2) during ***respiration*** (Go to page 4)

2) The remaining animal parts get buried under mud during a landslide (Go to page 21)

you travel, record where you have visited, an estimate of how long you stayed and then how you left on the worksheet. Some of the more difficult or new words are ***bold and italic*** and are defined in the glossary at the back of the book.

Have fun!

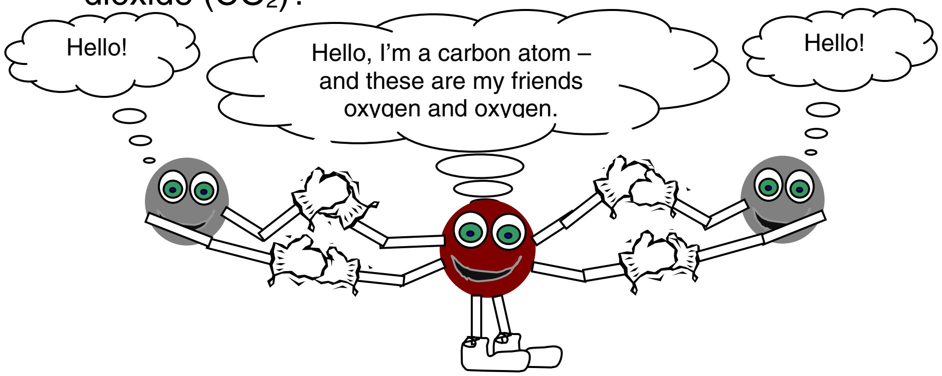
The GLOBE Carbon Cycle Team



Investigating the Carbon Cycle in Terrestrial Ecosystems

Carbon Cycle

Okay, so we're here with a carbon atom floating in the atmosphere connected to 2 oxygen atoms. Do you remember that this molecule is called carbon dioxide (CO_2)?



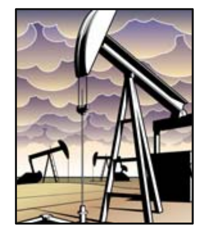
Carbon dioxide is one of the gases in Earth's atmosphere – it's called a trace gas because there isn't very much of it. Despite being a trace gas CO_2 is really important because it is also a greenhouse gas (like water vapor). Greenhouse gases naturally exist and act much like the glass on an actual greenhouse, which allows light to pass through to the world below, but also prevents much of the heat from leaving. Unfortunately, there is more and more carbon dioxide making its way to the atmosphere – which could make Earth's surface too warm. CO_2 molecules stay in the atmosphere for almost 100 years. Fortunately there are some ways that CO_2 leaves the atmosphere. So, where to from here?

1) Enter a plant leaf during ***photosynthesis*** (Go to page 5)

2) Enter the ocean (Go to page 6)

The tree has become buried under many layers of soil. It's dark and there isn't any oxygen here. Nothing much is happening to us now – it seems the carbon is stuck.

After many millions of years the tree limb has been reduced to fine ***sediments***. Compaction and hardening of these sediments result in sedimentary rock, such as shale. As the layers of sediment build up, both on land and in the oceans, heat and pressure increases, sometimes it's just too much and the carbon can turn into coal or oil. These are both made up of long chains of carbon atoms with hydrogen atoms attached on two sides. All together they are called ***hydrocarbons***.

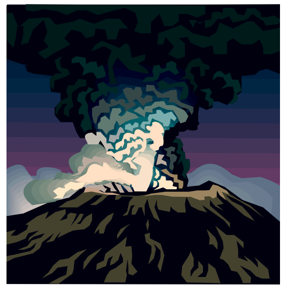


These, however, take millions of years to develop and then are stored deep below ground for another million or more years – unless the hydrocarbon might be pumped from the deep earth, processed as petrol or gasoline and burned in an ***internal combustion engine***, such as a car.

From here the carbon atom moves to the atmosphere as carbon monoxide (CO), made up of one carbon atom and one oxygen atom. It will meet another oxygen atom to create carbon dioxide (CO_2).

Return to the atmosphere as carbon dioxide (CO_2) (Go to page 4)

As the calcium carbonate molecule ($CaCO_3$) makes it to the bottom of the ocean it begins to link with other molecules of calcium carbonate to form a limestone rock layer. We could stay in this rock layer for millions of years. It's not very interesting here – but this keeps us out of the atmosphere!



Eventually, the carbon atom might be sent back to the atmosphere. Volcanic action releases carbon dioxide and methane from the vaporizing rock. Shifting land might also expose the limestone rock to the atmosphere; if this happens weathering could help return the carbon to the atmosphere.

1) Return to the atmosphere as carbon dioxide (CO_2) (Go to page 4)

2) Return to the atmosphere as methane (CH_4) (Go to page 12)

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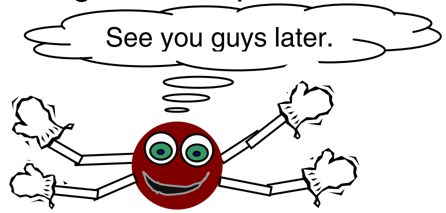
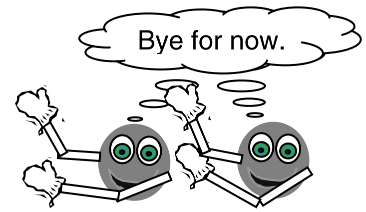
We have just followed the carbon dioxide molecule into the leaf of a small tree. There seem to be more carbon dioxide molecules here. Many water molecules (H_2O) and some sunlight energy is here too. It looks like the carbon dioxide molecules are being broken up into carbon (C) and oxygen (O_2).





Now the carbon atoms are being connected to water molecules to form glucose, a simple sugar ($C_6H_{12}O_6$). Glucose gives the tree energy that helps it grow and produce fruits. Some of the carbon atoms in the glucose exit the leaf as carbon dioxide during ***respiration*** while other carbon atoms are used to make important parts of the tree, such as additional leaves or wood. Carbon atoms that remain in leaves will either fall off (during ***senescence***) or become a meal for an animal. Also the tree will eventually die and ***decompose***.

1) The tree leaf is eaten (Go to page 7)

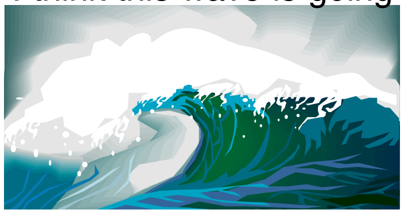
2) Return to the atmosphere during respiration (Go to page 4)

3) Stay in the tree until the tree dies (Go to page 10)

4) Fire burns the tree; return to the atmosphere as carbon dioxide (CO_2) (Go to page 4)

5) The leaf falls to the ground (Go to page 24)

We are now moving close to the surface of the North Atlantic Ocean. It's cold and very windy here and the waves are huge! There is a lot of mixing of the atmosphere and the ocean here. It's almost like the ocean is swallowing big gulps of air – CO_2 molecules just dissolve right into the water. Hold your nose – I think this wave is going to glub, glub, glub….



Wow! That was a huge wave! Now we're swirling around under water with the carbon dioxide (CO_2) molecule. There are many other carbon dioxide molecules here in the ocean.

Many of the CO_2 molecules moving down farther in the water. I can see many others entering aquatic plants, like ***phytoplankton*** (very tiny and can only be viewed with a microscope) and aquatic plants like seaweeds (known as macrophytes) through ***photosynthesis***. I never expected to see carbon in the ocean!

1) Enter a tiny marine organism, phytoplankton, during photosynthesis (Go to page 14)

2) Enter a marine plant, such as seaweed or algae, during photosynthesis (Go to page 8)

3) Move farther under water (Go to page 15)

4) Return to the atmosphere (Go to page 4)

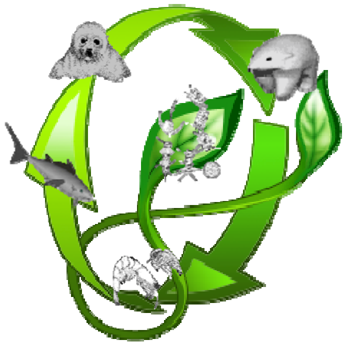
As the tree ***decomposed*** the carbon atom became buried in soil. It's very wet here with all of the decomposing leaves and parts of trees. There are also many thousands of ***microorganisms*** – very small animals and bacteria – in the soil. These microorganisms help to decompose the parts of plants. This makes more nutrients such as nitrogen, available to be used by new plants. The carbon however is respired by the microorganisms so we may find ourselves moving back into the atmosphere.

Much of the decaying plant material added to the surface of the soil is almost completely eaten by microorganisms. As more decaying plants cover the ground the partially decomposed material is forced to move down in the soil. There isn't as much oxygen down here so decomposition happens more slowly if at all. As the un-decomposed matter gets buried quickly by a landslide or slowly by new tree litter the carbon becomes locked away for hundreds to even a thousand years.

1) Move back into the atmosphere as carbon dioxide (CO_2) during ***respiration*** (Go to page 4)

2) The remaining tree parts get buried under mud during a landslide (Go to page 21)

The carbon atom has now entered the marine food web. As it moves from plant to animal to animal its form may change – it might combine with water molecules (H_2O) to form the simple sugar called glucose ($C_6H_{12}O_6$) or leave any of the animals along the food web as carbon dioxide (CO_2) through ***respiration***.



It is very exciting to move with carbon from organism to organism! Every plant and animal within the food web is made up of molecules containing carbon – from tiny ***phytoplankton*** to the polar bear. I think I'm beginning to understand why carbon is called the "Building Block of Life." We have followed the carbon atom as it moved along the food web all the way to the polar bear. It could have taken many different paths to reach this point.

1) Leave the food web as carbon dioxide (CO_2) during respiration (Go to page 4)

2) Leave the food web as methane (CH4) when waste is produced (Go to page 12)

3) Stay in the bear until it dies (Go to page 22)

Hi again! Well, here we are in an antelope's stomach with our carbon atom. The antelope, a herbivore (plant-eating animal), ate the leaf that our carbon atom was a part of – now the carbon atom is a part of the ***cellulose*** being broken down, or digested, by bacteria in the intestines of the antelope.

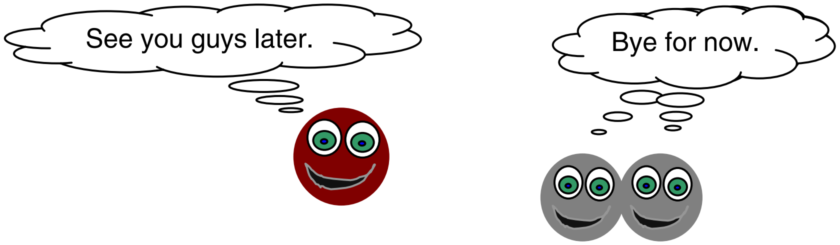
After this digestion the carbon atom might end up as an acid (such as acetic or butyric acid) to be used by the animal for energy or it might leave the antelope to return to the atmosphere as carbon dioxide (CO_2) or methane (CH_4).

1) Leave the antelope as carbon dioxide (CO_2) during ***respiration*** (Go to page 4)

2) Leave the antelope as methane (CH_4) when waste is produced (Go to page 12)

3) Be absorbed into the antelope (Go to page 13)

We've just followed the carbon dioxide (CO_2) molecule into the leaf of a seaweed. There seem to be many CO_2 molecules here; and of course many water molecules (H_2O), too. The sunlight reaches us here just below the surface. The carbon dioxide molecules are being broken up into carbon (C) and oxygen (O_2).



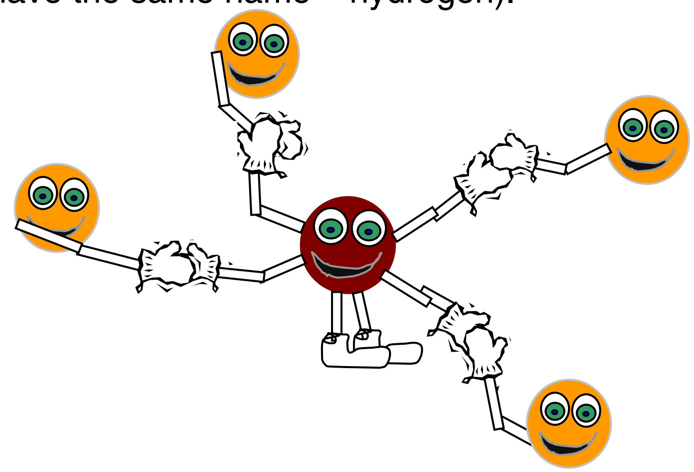
The carbon atoms are being connected to water molecules to form glucose, a simple sugar ($C_6H_{12}O_6$). Glucose gives the marine plant energy that helps it grow and produce more marine plants. Some of the carbon atoms in the glucose exit the leaf as carbon dioxide during *respiration* but others are used to make important parts of the plant. The plant might be eaten by a marine animal or it will eventually die, maybe falling to the bottom and *decomposing*. This releases CO_2.

1) The plant leaf is eaten (Go to page 9)

2) Return to the ocean as carbon dioxide (CO_2) during respiration (Go to page 16)

3) Return to the ocean as methane (CH_4) during decomposition (Go to page 17)

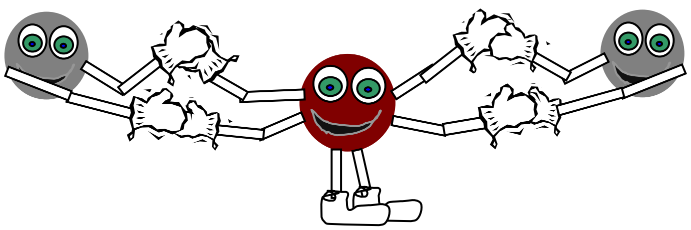
Carbon has found its way back to the ocean water. But instead of connected to two oxygen atoms it's now with four other friends – hydrogen (they all have the same name – hydrogen).



When these atoms are together they're called methane (CH_4). Just like when carbon is with its friends oxygen as CO_2, when CH_4 is in the atmosphere it reflects and absorbs some light from the Sun and trap heat reflected from the Earth's surface. It is a greenhouse gas like carbon dioxide (CO_2). However, while in the ocean it really can't cause any problems.

Methane changes to carbon dioxide (Go to page 16)

So, we're here with a carbon dioxide (CO_2) molecule floating in the water after being released by plant ***respiration***. Plant respiration is the reverse of ***photosynthesis***. During photosynthesis, CO_2 is taken in by the plant leaf and combined with water (H_2O) molecules and energy from sunlight to make glucose ($C_6H_{12}O_6$) for the plant to use. Oxygen is released during photosynthesis. During respiration, oxygen is taken in by the plant and glucose is used for energy. Carbon dioxide is released during plant respiration.



From the ocean's surface waters there are many places we can go….

1) Enter a marine plant, such as seaweed or algae, during photosynthesis (Go to page 8)

2) Enter a very small marine organism (called ***phytoplankton***) during photosynthesis (Go to page 14)

3) Move farther under water (Go to page 15)

Or

4) Re-enter the atmosphere (Go to page 4)

DRAFT – 10_10_08

Hello again! The part of the marine plant that our carbon at was a part of was just eaten by a fish. So, here we are in the herbivorous (plant-eating) fish's stomach. Now the carbon atom is a part of the ***cellulose*** being broken down, or digested, by bacteria in the intestines of the fish.

After this digestion the carbon atom might end up as an acid (such as acetic or butyric acid) to be used by the fish for energy or it might leave the fish to return to the ocean as carbon dioxide (CO_2) or methane (CH_4).

1) Leave the fish as carbon dioxide (CO_2) during ***respiration*** (Go to page 16)

2) Leave the fish as methane (CH_4) when waste is produced (Go to page 17)

3) Become part of the marine food web (Go to page 18)

4) Stay in the fish until it dies (Go to page 22)

It's been nearly 100 years that the carbon atom has been in this tree. When it entered into the leaf many years ago the plant was just a small sapling – just beginning to grow from leaf to wood.

Now that the tree is at the end of its life it's huge! I wonder how many carbon atoms have come and gone. Probably more than we can count! This tree, our home for nearly 100 years, has helped to keep many carbon dioxide (CO_2) molecules out of the atmosphere. But now that the tree is dead the carbon atom will need to move someplace else.

Laying on the ground makes it is easy for carbon to get moved many places! The dead tree might be ***decomposed*** by ***microorganisms***, eaten by small animals, or slowly buried beneath more and more layers of plant litter. A fire could even come through and send it quickly back to the atmosphere.

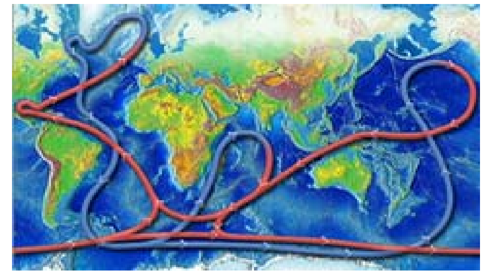
1) Become buried in soil (Go to page 19)

2) Return to the atmosphere as CO_2 during ***respiration*** by microorganisms (Go to page 4)

3) Be eaten by a beetle (Go to page 11)

4) Fire burns the dead tree; return to the atmosphere as carbon dioxide (Go to page 4)

Our CO_2 molecule is moving down under water with many other molecules, being pulled down by a current to the cold deep water, until it is at the bottom of the Northern ocean. It has joined the ***thermohaline current***, or the ocean conveyor belt.



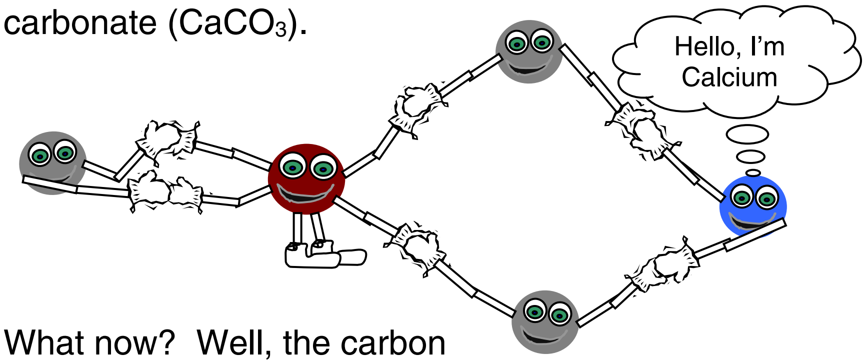
Source: http://oceanservice.noaa.gov/education

We travel with our molecule from the cold North Atlantic Ocean across the Equator and down to the cold Southern ocean (where the Atlantic, Indian and Pacific oceans meet) along Antarctica and then up to the Pacific Ocean. By the time we reach the North Pacific Ocean it will have warmed up a little; we'll rise with our CO_2 molecule closer to the surface. Some CO_2 will be released to the atmosphere through a process known as upwelling. Other CO_2 molecules will continue to travel along the southern part of Asia, through the Indian Ocean, past southern Africa and then cross the Equator once again to reach the North Atlantic. The entire journey could last close to a thousand years!

Remain in the thermohaline current for the whole journey, then move into the atmosphere just above the surface of the North Atlantic Ocean. (Go to Page 6)

We have just followed the carbon dioxide (CO_2) molecule into a small plant-like organism called *phytoplankton*. There are other atoms and molecules here too. Moving around in the water causes our carbon dioxide molecule to become connected to a hydrogen atom and another oxygen atom. This molecule is called bicarbonate (HCO_3). I see some calcium (Ca) atoms here too.

In some phytoplankton, bicarbonate and calcium atoms can chemically combine to make a skeleton or shell. If we do this, we are called calcium carbonate ($CaCO_3$).

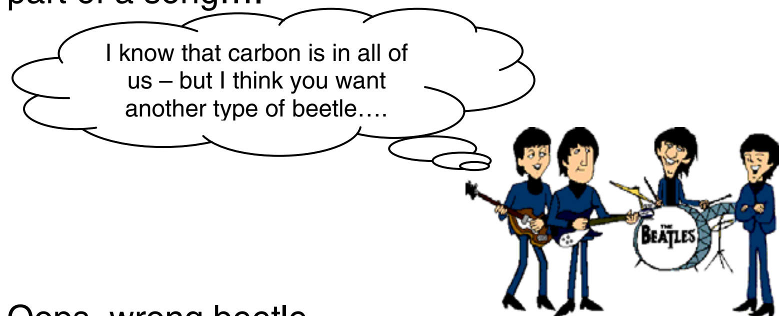


What now? Well, the carbon atom could remain as a part of calcium carbonate for a long time. Even after the phytoplankton dies it might fall to the bottom of the ocean and become part of the limestone layer for hundreds to thousands of years. Or it could be eaten and enter the food web.

1) Fall to the bottom of the ocean to form a limestone rock layer (Go to page 20)

2) Become part of the marine food web (Go to page 18)

Hello! Well, it is an honor to be here inside of a Beatle! Perhaps the carbon atom will end up as part of a song….



Oops, wrong beetle. Source: http://beatlesnumber9.com/graphics.html

Sorry for the mistake…. So, here we are inside of a

beetle! Beetles and other small animals eat pieces of leaf and wood that have fallen to the ground – and now it's heading to the intestines where bacteria will begin to break down, or digest, the ***cellulose***.

After this digestion the carbon atom might end up as part of an acid to be used by the beetle for energy or it might leave the animal to return to the atmosphere as carbon dioxide (CO_2) or methane (CH_4).

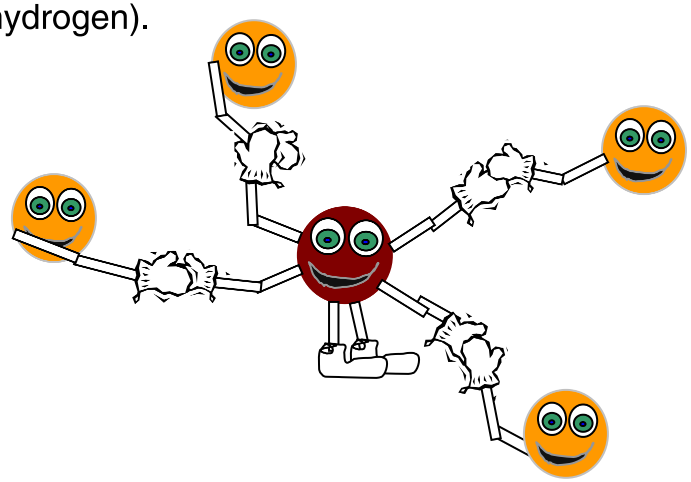
1) Leave the beetle as carbon dioxide (CO_2) during ***respiration*** (Go to page 4)

2) Leave the beetle as methane (CH_4) when waste is produced (Go to page 12)

3) Stay in the beetle until it dies (Go to page 22)

4) Become part of the ***terrestrial*** food web (Go to page 23)

Wow! Carbon has found its way back to the atmosphere. But instead of connected to two oxygen atoms it's now with four other friends – hydrogen (they all have the same name, hydrogen).



When these atoms are together they're called methane (CH_4). Just like when carbon is with its friends oxygen as CO_2, when it gets into the atmosphere as CH_4 it seems to wrap the Earth like a blanket and keep the heat in. In case you haven't figured it out, methane is also a greenhouse gas. Like CO_2 it also naturally exists; it can reflect some light from the sun and let some heat from the Earth pass through. But if too many methane molecules are up here in the atmosphere they will make the blanket thicker and cause the Earth to get too hot.

Methane (CH_4) changes to carbon dioxide (CO_2) in the atmosphere after about 5 – 10 years (Go to page 4)

DRAFT – 10_10_08

After the carbon atom has gone through the digestion process it is absorbed into the blood stream and carried through the body to reach the cells. Carbon in the bloodstream can enter cells through the cell walls. At this point it might become stored as fat cells – waiting to be used by animals for energy.

Maybe it'll be used for energy to run across the savanna!

I wonder what will happen….

1) Leave the antelope as carbon dioxide (CO_2) during *respiration* (Go to page 4)

2) Leave the antelope as methane (CH_4) when waste is produced (Go to page 12)

3) Become part of the *terrestrial* food web (Go to page 23)

4) Stay in the antelope until it dies (Go to page 22)