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, NOAA and NSF Earth System Science Projects (ESSPs) in study and research about the dynamics of Earth's environment. From its inception in 1994, the international GLOBE network has grown to include representatives from over 100 participating countries and approximately 150 U.S. partners coordinating GLOBE activities that are integrated into their local and regional communities.

The GLOBE Carbon Cycle ESSP joins NASA-funded carbon cycle scientists with the GLOBE Program to bring cutting-edge research and research techniques in the field of terrestrial ecosystem carbon cycling into secondary classrooms. As part of this project students collect data about their school field site to determine carbon storage and participate in classroom activities to understand carbon cycling. Students also have the opportunity to integrate their data with emerging and expanding technologies, including global and local carbon cycle computer models and online map resources. This program design allows students to explore research questions from local to global scales under both present and future environmental conditions.

www.globe.gov

Can you...

Follow the Carbon Atom?

A self-guided adventure through the Carbon Cycle

THE GLOBE PROGRAM

GLOBE® 2017 Carbon Cycle Biosphere

Glossary of Terms

Atom – The smallest particle of an element.

Cellulose – A carbohydrate made up of glucose molecules forming the main part of the cell wall in most plants.

Decomposition – The process of decay, breaking down into basic elements.

Exoskeleton – An external skeleton that supports/protects an animal's body.

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

Microorganism – An organism too small to see without magnification, sometimes called a **microbe**.

Organic matter – One living material composed of compounds built around a structure of carbon atoms.

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

Phytoplankton – Tiny aquatic plants. Many are too small to see without magnification. These organisms get their energy from photosynthesis.

Plant senescence – The study of aging in plants. As part of the plant (leaves) ages plants try to save valuable resources (glucose, water, etc.) by cutting off nutrients to dying parts (one reason why leaves turn colors.

Respiration – The release of carbon dioxide as organic (carbon-based) compounds are broken down and used for energy by organisms. It can be thought of as the reverse of photosynthesis. Oxygen is taken in to use with stored carbohydrates as energy. Carbon dioxide and water are produced.

Sediment – Material that settles to the bottom of a liquid (e.g. soil particles and dead plankton falling to the bottom of the sea).

Terrestrial – Living or growing on land**.**

Thermohaline circulation – The movement of deep water in the oceans driven by differences in density, caused by salinity and temperature.

Upwelling – The wind-driven movement of colder, denser nutrient rich water from the deep to the surface of the ocean.

Weathering – The physical and chemical processes that break solid rock into tiny particles that can be moved to other places as sediment.

"After I participated in ***photosynthesis*** in the leaf and helped to form the simple sugar glucose I then joined with many other glucose molecules to create ***cellulose***, which helps to build cell walls and other rigid structures. But I guess all good things must end and now it is time to move on. Plus, it should be an exciting journey from this leaf to the soil surface."

A leaf laying on the soil surface makes it easy for carbon to move to many different places. The leaf might be eaten by small animals and ***microorganisms***, slowly become buried beneath more and more layers of plant litter (leaves and twigs), or a fire could even come through and send it quickly back to the atmosphere.

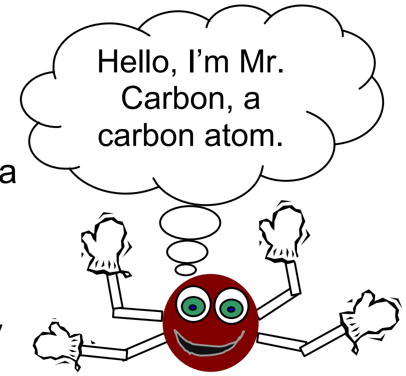
1) Become <u>incorporated</u> into the organic layers near the soil surface (Go to page 19)

2) Be <u>eaten</u> by a beetle (Go to page 11)

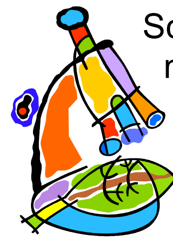
3) Fire <u>burns</u> the leaf; return to the atmosphere as carbon dioxide (Go to page 4)

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.

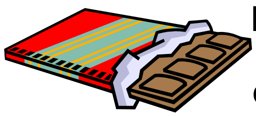


Scientists use strong microscopes to see very small things but even strong microscopes can't see single atoms.

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!

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

Carbon can also be found in the Earth's atmosphere (the air we breathe), the soil that we walk on, in the oceans and other water bodies, 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 common 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 that contain carbon. But maybe we should get back to our story.



When carbon joins with these other elements the resulting molecules can be in the form of a solid, a liquid or a gas. Over time, a single carbon atom can be joined with, and released from, many different substances. 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.

"I can't believe I've entered the ***terrestrial*** food web. It is very exciting to move from organism to organism! As I move from plant to animal to animal I get to change form– I could 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***."

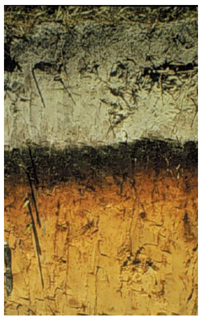
Every plant and animal within the food web is made up of molecules containing carbon – from tiny bacteria to the lion and everywhere in between. This is why the description of carbon as the "Building Block of Life" is so appropriate.

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

2) Leave the food web as methane (CH_4) during <u>waste production</u> (Go to page 12)

3) <u>Stay</u> in the lion's cells and tissues until it dies (Go to page 22)

At the soil surface thousands of ***microorganisms***, or microbes, are ready to break down ***organic matter*** into small particles through the process of ***decomposition***. Microbes use the available carbon from dead animal tissues for energy and release CO_2 back to the atmosphere during ***respiration***. Decomposition of organic matter also makes more nutrients, like nitrogen, available to plants.



While microbes do their best at decomposition, some dead plants and animals build up at the soil surface. 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 there, decomposition happens more slowly. As plant litter buries un-decomposed matter slowly, the carbon becomes locked away in the soil for hundreds of years. If un-decomposed matter gets buried more quickly, as in the case of a landslide, intense heat and pressure, over time, can cause carbon to form ***hydrocarbons***.

1) Return to the atmosphere as carbon dioxide (CO_2) during <u>respiration</u> by microorganisms (Go to page 4)

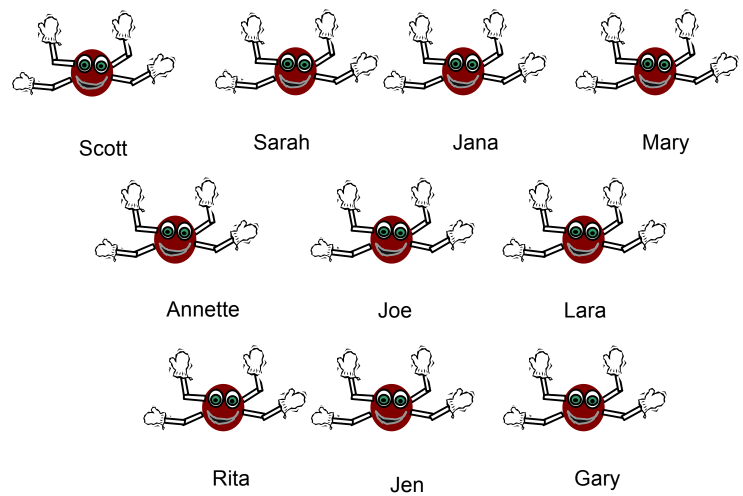
2) The remaining animal parts get <u>buried</u> under mud during a landslide (Go to page 21)

3) <u>Stay</u> in the soil attached to soil particles (Go to page 22)

You are about to take a journey through the global carbon cycle following our friend, Mr. Carbon, the 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 Mr. Carbon should travel next. As you travel, record where you have visited (carbon pools) and then how you left (carbon fluxes) in the *Carbon Story Journey Table*. Some of the more difficult, or new, words are ***bold and italic*** and defined in the glossary at the back of the book.

Have fun!

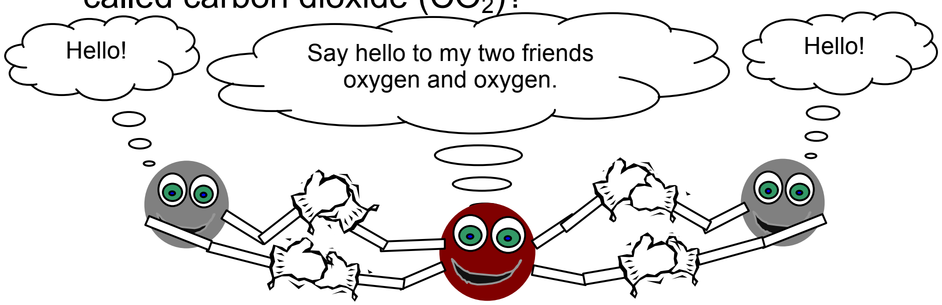
The GLOBE Carbon Cycle Team



Investigating the Carbon Cycle in Terrestrial Ecosystems

Carbon Cycle

“Welcome to the atmosphere! Have you met my two friends oxygen and oxygen? Do you remember that together we make a molecule 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. 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. “Where should we travel next?”

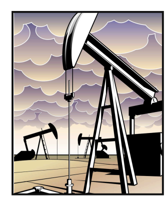
1) Enter a plant leaf during ***photosynthesis*** (Go to page 5)

2) Dissolve into the ocean (Go to page 6)

“It sure is dark in here, and there isn’t much oxygen either! What’s going to happen to me without any oxygen?”

Typically, as plant litter builds up on the soil surface, there is plenty of space, thus plenty of oxygen, between soil particles to allow complete ***decomposition*** of ***organic matter*** by ***microorgansims***. However, when there are events such as landslides or other conditions that prevent complete decomposition (such as very wet areas), carbon becomes trapped below other ***sediments***, such as sand, mud and rocks. Compaction due to the pressure from the layers of sediment above and heat due to the increasing pressure is what causes carbon to turn into coal or oil.

Carbon and oil are both made up of long chains of carbon ***atoms*** with hydrogen atoms attached on two sides. The carbon and hydrogen attached together are called ***hydrocarbons***.

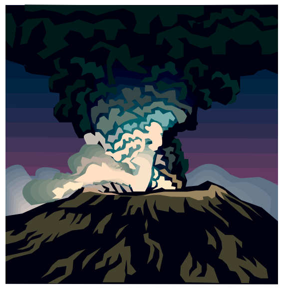


The carbon found in hydrocarbons of coal and oil are also called fossil fuels because they form deep below ground and take millions of years to develop Under normal conditions, they would almost never reach the surface except we mine it and pump it to be used in our cars, homes, factories, and airplanes.

1) Return to the atmosphere as CO_2 during the burning of coal and oil for fuel (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.

"Ah, a relaxing vacation. I think I'll stay in this rock layer for a million years or so. It's not very interesting here – but it keeps me out of the atmosphere!"

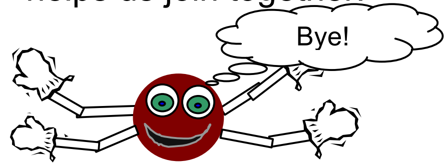


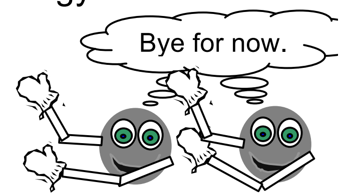
Eventually, a carbon atom will be sent back to the atmosphere through geologic processes. Extreme temperature and pressure will change rocks into new forms – some of which might play a role in volcanic action, which releases carbon dioxide and methane from the vaporizing rock. Shifting land (fault lines, earthquakes) might also expose buried rock to the atmosphere; if this happens, ***weathering*** by wind and rain could help return the carbon to the atmosphere.

1) <u>Geologic processes</u> return carbon dioxide to the atmosphere (Go to page 4)

2) <u>Geologic processes</u> return methane to the atmosphere (Go to page 12)

We have just followed Mr. Carbon, part of a carbon dioxide molecule, into the leaf of a small plant. "Now that I am in the plant, my friends oxygen must leave, but I am joined by some new friends, the water molecules (H_2O). Energy from the sun helps us join together!"





Carbon ***atoms*** connected to water molecules form glucose, a simple sugar ($C_6H_{12}O_6$). Glucose gives the plant 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 plant, such as additional leaves or wood. Carbon atoms that remain in leaves will either fall off (during ***plant senescence***) or become a meal for an animal. Also the plant will eventually die and ***decompose***. Where will you follow Mr. Carbon next?

1) The tree leaf is <u>eaten</u> (Go to page 7)

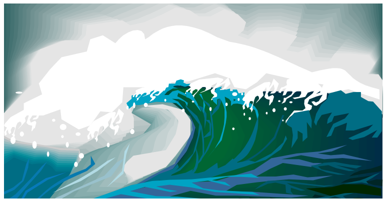
2) Return to the atmosphere during <u>respiration</u> (Go to page 4)

3) <u>Stay</u> in the plant cells and tissues until the plant dies (Go to page 10)

4) Fire <u>burns</u> the tree; return to the atmosphere as carbon dioxide (Go to page 4)

5) The leaf <u>falls</u> to the soil surface (Go to page 24)

"Well, here we are… 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 between the atmosphere and the ocean. It's almost like the ocean is swallowing big gulps of air – CO_2 molecules, like me, 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 and there are carbon dioxide molecules everywhere."

"Many of the CO_2 molecules are moving down farther in the water. Others are entering ***phytoplankton*** and aquatic plants like seaweeds through the process of ***photosynthesis***. I never expected the ocean to be so fun for carbon ***atoms***! Where should I go next?"

1) Enter 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 deeper under water through ocean mixing (Go to page 15)

4) Return to the atmosphere through ocean mixing (Go to page 4)

"Wow, the soil surface is very moist and things are breaking down very quickly! What a strange place this is. There is a lot of stuff around me, but it is hard to identify; ***decomposing*** plant parts including leaves, wood, and roots AND thousands of ***microorganisms*** – very small animals and bacteria."

Microorganisms help to decompose the parts of plants. They use the carbon in glucose as energy and respire carbon dioxide to the atmosphere while making nutrients, such as nitrogen, available in the soil to be used by new plants.

Much of the decaying plant material added to the surface of the soil is eaten by microorganisms. As more decaying plants cover the ground, the partially decomposed material is forced to move down in the soil. Because there isn't as much oxygen down there, decomposition happens more slowly. As plant litter buries un-decomposed matter slowly, the carbon becomes locked away in the soil for hundreds of years. If un-decomposed matter gets buried more quickly as in the case of a landslide, intense heat and pressure, over time, can cause carbon to form ***hydrocarbons***.

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

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

"How did I get stuck in this food web?"

When the carbon ***atom*** has entered the marine food web it moves from plant to animal to animal, etc., changing forms as it goes. It might combine with water molecules (H_2O) to form the simple sugar called glucose ($C_6H_{12}O_6$), enter the blood stream and become part of a cell, or leave any of the animals within the food web as carbon dioxide (CO_2) through ***respiration***.

"I had no idea that every plant and animal within the food web is made up of molecules containing carbon just like me. I think I'm beginning to understand why carbon is called the "Building Block of Life"."

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

2) Leave the food web as methane (CH_4) during <u>waste production</u> (Go to page 12)

3) <u>Stay</u> in the bear's cells and tissues until it dies (Go to page 22)

"Hi again! Well, here I am in an antelope's stomach."

The antelope, an herbivore (plant-eating animal), ate the leaf that the carbon ***atom*** was a part of and now it is being broken down, or digested, by bacteria in the intestines of the antelope.

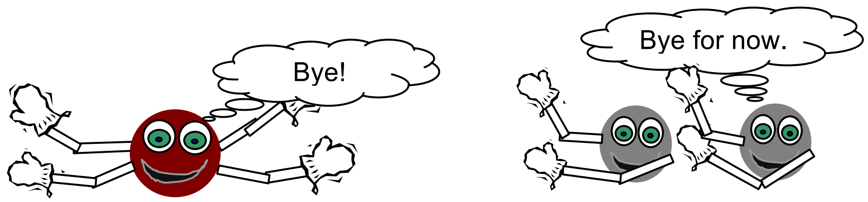
After this digestion the carbon atom might end up as an acid (such as acetic or butyric acid) to be used by the animal for energy or it might leave the antelope to return to the atmosphere as carbon dioxide (CO_2) or methane (CH_4).

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

2) Leave the antelope as methane (CH_4) during <u>waste production</u> (Go to page 12)

3) Be <u>absorbed</u> into the cells and tissues (muscles, fat, etc.) of the antelope (Go to page 13)

“I can’t believe we are in a seaweed! It is very busy here. It is now time to leave my friends oxygen and oxygen, but because the sunlight can reach me here I am able to join with new friends, water molecules (H_2O).”



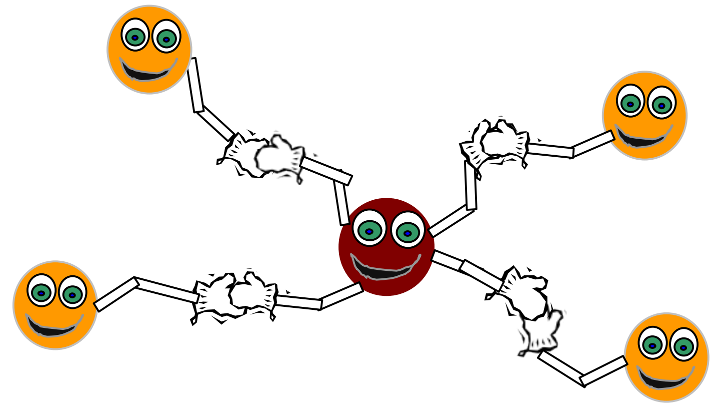
The carbon ***atoms*** are being connected to water molecules to form glucose, a simple sugar ($C_6H_{12}O_6$). Glucose gives the marine plant energy that helps it grow and produce more marine plants. Some of the carbon atoms in the glucose leave the leaf as carbon dioxide during ***respiration***, but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

1) The plant leaf is <u>eaten</u> (Go to page 9)

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

3) Return to the ocean as methane (CH_4) during <u>decomposition</u> (Go to page 17)

“Well, I seem to have made it back to the ocean water, but something is very different. Instead of being connected to two oxygen ***atoms*** I now have four new friends – they all have the same name, hydrogen.”

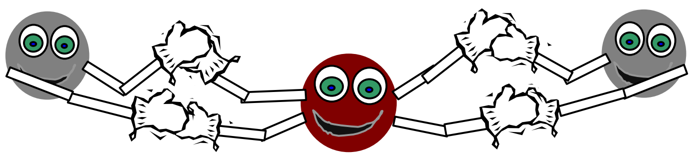


When these atoms are together they’re called methane (CH_4). Just like CO_2, when methane gets into the atmosphere, it seems to wrap the Earth like a blanket and keep the heat in. Because of this “blanket effect” methane is also a greenhouse gas. Like CO_2 it also naturally exists; it can reflect some light from the sun and let some heat from the Earth pass through. But if too many methane molecules are up in the atmosphere they will make the blanket thicker and cause the Earth to get too hot. However, while in the ocean it really can’t cause too many problems.

1) Methane <u>reverts</u> back to carbon dioxide in ocean water (Go to page 6)

"Back in the water again! It all happened so quickly. One minute in a plant and the next released during ***respiration***."

Plant ***respiration*** is the reverse of ***photosynthesis***. During photosynthesis, CO_2 is taken in by the plant leaf and combined with water molecules (H_2O) and energy from sunlight to make glucose ($C_6H_{12}O_6$) for the plant to use. Oxygen is released during photosynthesis. During respiration, the plant takes in oxygen and glucose is used for energy. Carbon dioxide is released during plant respiration.



"Where should I go next? From the ocean's surface waters there are many places to go…."

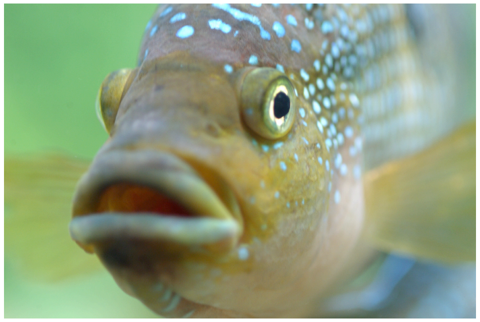
1) Enter a marine plant, such as seaweed or algae, during photosynthesis (Go to page 8)

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

3) Move farther under water by ocean mixing (Go to page 15)

4) Re-enter the atmosphere by ocean mixing (Go to page 4)

"Hello again! So, here we are in the herbivorous (plant-eating) fish's stomach."



The herbivorous (plant-eating) fish ate the leaf that Mr. Carbon was a part of and now he is being broken down, or digested, by bacteria in the intestines of the fish.

After this digestion Mr. Carbon 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).

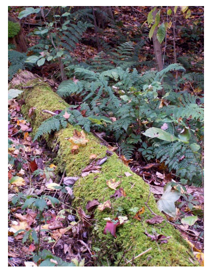
1) Leave the fish as carbon dioxide (CO_2) during ***respiration*** (Go to page 16)

2) Leave the fish as methane (CH_4) during waste production (Go to page 17)

3) Be eaten and become part of the marine food web (Go to page 18)

4) Be absorbed into the cells and tissues of the fish until it dies (Go to page 22)

"I can't believe I have been locked in the tissues (such as ***cellulose***) of this plant for so many years! When I first entered into the leaf, the plant was just a small seedling – just beginning to grow. I guess I am lucky though. If I had been incorporated into a tree instead, I might have lived in there for 100 years or more without moving on!"



Trees are a great way for carbon to stay out of the atmosphere for a while. Eventually, though, all plants of all sizes must die and when they do, carbon is transferred to the soil surface or back to the atmosphere.

Laying on the ground makes it 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 incorporated in soil as layers of litter build up (Go to page 19)

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

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

"Now it seems that I am moving deeper into the ocean water, I bet it is because the water is so cold! Because I am in the northern ocean I must be joining the ocean's conveyor belt, a process called ***thermohaline circulation***. If this is true I will travel the world!"

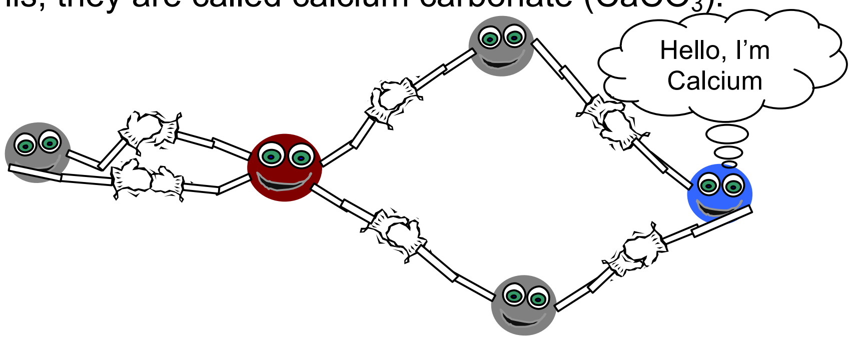
Source: http://oceanservice.noaa.gov/education

Thermohaline circulation works like a conveyor belt moving cold North Atlantic Ocean water across the Equator and down to the southern ocean (where the Atlantic, Indian and Pacific oceans meet) along Antarctica and then up to the Pacific Ocean. By the time water reaches the North Pacific Ocean it has warmed up a little; this warmer water will rise closer to the ocean surface bringing some CO_2 molecules and other nutrients with it, in 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!

1) Become part of thermohaline circulation for a complete cycle around the world's oceans, slowly returning to the ocean surface through upwelling (Go to Page 6)

"Wow, what a trip! Getting into such a tiny organism like ***phytoplankton*** is quite the ride. Now that I'm here as a carbon dioxide molecule I notice there are lots of other ***atoms*** and molecules here too. Some carbon is being used for energy as part of glucose and some is joining with some other molecules. It looks like I'll join with a hydrogen and some oxygen atoms to form bicarbonate (HCO_3)."

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



A 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 rock layer for hundreds to thousands of years. Or it could be eaten and enter the marine food web.

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

2) Be <u>eaten</u> and become part of the marine food web (Go to page 18)

"Cool! I'm inside of a Beatle! Perhaps I will be used as energy to create a song…"

Source: http://beatlesnumber9.com/graphics.html

"Oops, wrong beetle. Sorry for the mistake…."

Beetles and other small animals eat pieces of leaves and wood that have fallen to the ground. Once these particles have traveled to the intestines, bacteria break down, or digest, the carbon compounds such as ***cellulose***.

During digestion, a carbon ***atom*** might end up as part of an acid to be used by the beetle for energy, or it might leave the animal and return to the atmosphere as carbon dioxide or methane. Where should Mr. Carbon go next?

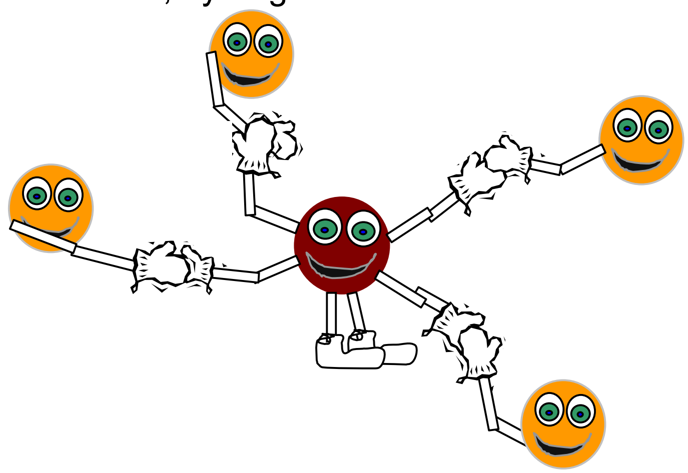
1) Leave the beetle as carbon dioxide (CO_2) during <u>***respiration***</u> (Go to page 4)

2) Leave the beetle as methane (CH_4) during <u>waste production</u> (Go to page 12)

3) Be <u>absorbed</u> into the beetle's tissues (perhaps as its ***exoskeleton***) until it dies (Go to page 22)

4) Be <u>eaten</u> and become part of the ***terrestrial*** food web (Go to page 23)

“Well, I seem to have made it back to the atmosphere, but something is very different. Instead of being connected to two oxygen ***atoms*** I now have four new friends – they all have the same name, hydrogen.”



When these atoms are together they’re called methane (CH_4). Just like when carbon is with 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. Because of this “blanket effect,” 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 in the atmosphere, they will make the blanket thicker and cause the Earth to get too hot.

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

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 Mr. Carbon might become stored as fat cells – waiting to be used by the animal for energy.

“Maybe I’ll be used for energy to run across the savanna!”

“I can’t wait for more adventure…”

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

2) Leave the antelope as methane (CH_4) during waste production (Go to page 12)

3) Be eaten and become part of the ***terrestrial*** food web (Go to page 23)

4) Stay in the antelope’s cells and tissues until it dies (Go to page 22)