What is the carbon cycle?

By NASA Earth Observatory, adapted by Newsela staff on 03.29.17
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Carbon is both the foundation of all life on Earth and the source of the majority of energy consumed by human civilization. Swamp ecosystems like this one in Norway are a carbon sink that take carbon out of the atmosphere. Photo: Pixabay/Public Domain

Carbon is the backbone of life on Earth. We are made of carbon, we eat carbon, and our civilizations — our economies, our homes, our means of transport — are built on carbon. We need carbon, but that need is also connected with one of our most serious problems: global climate change.

Carbon is the fourth most abundant element in the universe. Most of Earth's carbon — about 65,500 billion metric tons — is stored in rocks. The rest is in the ocean, atmosphere, plants, soil and fossil fuels.

Carbon flows between each of them in an exchange called the carbon cycle. There is both a slow carbon cycle and a fast carbon cycle. Any change in the cycle that shifts carbon out of one area puts more carbon in the others. When carbon gases end up in the atmosphere, temperatures get warmer on Earth.

Over the long term, the carbon cycle seems to maintain a balance. This balance helps keep Earth's temperature relatively stable, like a thermostat. This thermostat works over a few hundred thousand years, as part of the slow carbon cycle. This means that for shorter time periods, from tens to a hundred thousand years, the temperature of Earth can vary. The Earth swings between ice ages and warmer interglacial periods on this time scale.

Over much longer periods of millions or tens of millions of years, the temperature may change more dramatically. Earth has undergone such a change over the last 50 million years.

The Slow And Steady Cycle Begins With Rain

Carbon takes 100 to 200 million years to move between rocks, soil, ocean and atmosphere in the slow carbon cycle. On average, 10 to 100 million metric tons of carbon move through the slow carbon cycle every year. In comparison, human emissions of carbon to the atmosphere are 10 to 100 times more than that.

The movement of carbon from the atmosphere to rocks begins with rain. Atmospheric carbon combines with water to form a weak acid that falls to the surface in rain. The acid dissolves rocks and releases calcium, magnesium, potassium or sodium. Rivers carry them to the ocean.

In the ocean, the calcium is combined with bicarbonate ions to form calcium carbonate. In the modern ocean, most of the calcium carbonate is made by shell-building creatures, such as corals, and plankton. After they die, they sink to the seafloor, and over time, layers of shells and minerals are cemented together and turn to rock, storing the carbon in limestone.

Only 80 percent of carbon-containing rock is currently made this way. The remaining 20 percent contains carbon from living things that have been embedded in layers of mud. Over millions of years, heat and pressure on the mud and carbon form sedimentary rock such as shale. In special cases, when dead plant matter builds up faster than it can break down, layers of carbon become oil, coal or natural gas instead of sedimentary rock.

The slow cycle returns carbon to the atmosphere through volcanoes. When volcanoes erupt, they vent the carbon dioxide to the atmosphere and cover the land with fresh rock to begin the cycle again. At present, humans release about 100 to 300 times more carbon dioxide than volcanoes by burning fossil fuels.

If volcanoes raise the carbon dioxide in the atmosphere, temperatures rise, leading to more rain. That dissolves more rock, which will eventually deposit more carbon on the ocean floor. This takes a few hundred thousand years to rebalance.

However, the slow carbon cycle also contains a slightly faster part: the ocean. The ocean absorbs and ventilates carbon dioxide at the surface. Once in the ocean, carbon dioxide gas reacts to make the ocean more acidic.

Since human activity has increased carbon concentrations in the atmosphere, the ocean now takes more carbon from the atmosphere than it releases. Over thousands of years, the ocean will absorb up to 85 percent of the extra carbon, but the process is slow because it is tied to the movement of water from the ocean's surface to its depths. Changes in ocean temperatures and ocean currents probably helped remove carbon from and then restore it to the atmosphere over the few thousand years in which the ice ages began and ended.

Plants, Phytoplankton Are Key To Fast Carbon Cycle

The fast carbon cycle is largely the movement of carbon through life forms on Earth. Between 1,000 to 100,000 million metric tons of carbon move through the fast carbon cycle every year.

Carbon plays an essential role in life on Earth. That's because carbon can form up to four bonds per atom in what seems like an endless variety of complex organic molecules. For instance, DNA is made of two intertwined molecules built around a carbon chain. The bonds in the long carbon chains contain a lot of energy. When the chains break apart, the stored energy is released. This energy makes carbon molecules an excellent source of fuel for all living things.

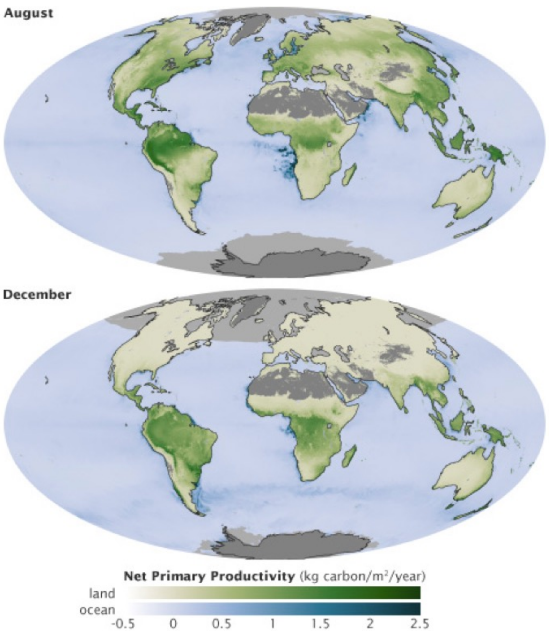
Plants and phytoplankton are the main parts of the fast carbon cycle. Phytoplankton, which are microscopic organisms in the ocean, and plants take carbon dioxide from the atmosphere by absorbing it into their cells. They use energy from the sun and combine carbon dioxide (CO_2) and water to form sugar (CH_2O) and oxygen. The chemical reaction looks like this:

$CO_2 + H_2O + \text{energy} = CH_2O + O_2$

Four things can happen to move carbon from a plant and return it to the atmosphere. Plants break down the sugar to get the energy they need to grow. Animals (including people) eat the plants or plankton, and break down the plant sugar to get energy. Plants and plankton die or decay at the end of the growing season. Or, fire consumes plants. In each case, oxygen combines with sugar to release water, carbon dioxide and energy. The basic chemical reaction looks like this:

$CH_2O + O_2 = CO_2 + H_2O + \text{energy}$

In all four processes, the carbon dioxide released in the reaction usually ends up in the atmosphere. The fast carbon cycle is very closely tied to plant life. As a result, the growing season can be seen by the way carbon dioxide fluctuates in the atmosphere. In the Northern Hemisphere winter, few land plants are growing and many are decaying, so atmospheric concentrations climb. During the spring, when plants begin growing again, concentrations drop. It is as if the Earth is literally breathing.



The fast carbon cycle is visible in the changing seasons. As the large land masses of Northern Hemisphere green in the spring and summer, they draw carbon out of the atmosphere.

These maps show the amount of carbon consumed by plants on land (green) and in the oceans (blue) during August and December, 2010. In August, the green areas of North America, Europe, and Asia represent plants using carbon from the atmosphere to grow.

Graph by Marit Jentoft-Nilsen and Robert Simmon, using data from the NOAA Earth System Research Laboratory. Maps by Robert Simmon and Reto Stöckli/NASA.

Cycle Responds To Changing Temperatures

Left undisturbed, the fast and slow carbon cycles maintain a relatively steady concentration of carbon in the atmosphere, land, plants and ocean. When anything changes the amount of carbon in one area, though, the effect ripples through the others.

Throughout Earth's history, the carbon cycle has changed in response to the changing climate. When the Earth gets cooler, the carbon cycle slows. The carbon in the atmosphere decreases, and that causes additional cooling. The opposite happens when temperatures rise.

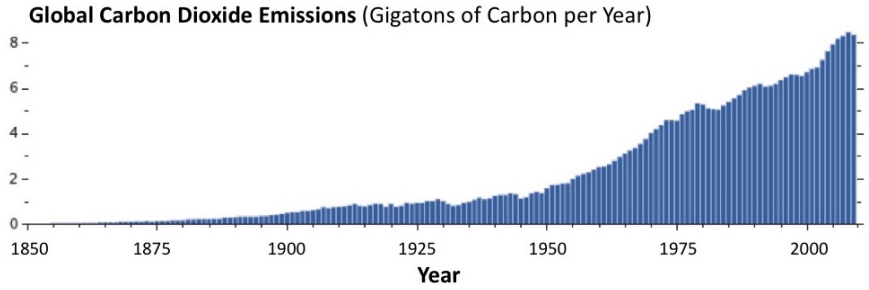
Today, changes in the carbon cycle are happening because of people. We affect the carbon cycle by burning fossil fuels and clearing land.

When we clear forests, we eliminate plants that would otherwise take carbon out of the atmosphere as they grow. We also expose soil that vents carbon from decayed plant matter into the atmosphere. Humans are currently emitting just under a billion tons of carbon into the atmosphere per year through land use changes.

Without human interference, the carbon in fossil fuels would leak slowly into the atmosphere over millions of years. By burning coal, oil and natural gas, we accelerate the process, releasing vast amounts of carbon that took millions of years to accumulate into the atmosphere every year. By doing so, we move the carbon from the slow cycle to the fast cycle.

Land, Plants And The Ocean Soak Up Extra Carbon

Since people first started burning fossil fuels, carbon dioxide concentrations in the atmosphere have risen by 39 percent, the highest concentration in two million years. The concentration has risen from about 280 parts per million (ppm) to around 400 parts per million. That means that for every million molecules in the atmosphere, 400 of them are now carbon dioxide.



Emissions of carbon dioxide by humanity have been growing steadily since the onset of the industrial revolution. About half of these emissions are removed by the fast carbon cycle each year, the rest remain in the atmosphere. Graph: NASA.

All of this extra carbon needs to go somewhere. So far, land, plants, and the ocean have taken up about 55 percent of the extra carbon people have put into the atmosphere while about 45 percent has stayed in the atmosphere. Eventually, the land and oceans will take up most of the extra carbon dioxide, but as much as 20 percent may remain in the atmosphere for many thousands of years.

Excess carbon in the atmosphere warms the planet and helps plants on land grow more. Excess carbon in the ocean makes the water more acidic, putting marine life in danger.

Quiz

1 Which idea is BEST supported by the last paragraph of the section "Cycle Responds To Changing Temperatures"?

(A) The huge amount of carbon that humans release into the atmosphere is damaging to the environment.

(B) Human activity disrupts the carbon cycle by increasing the amount of carbon in the atmosphere.

(C) Without human activity, the slow carbon cycle would be able to regulate the earth's temperature.

(D) When the carbon cycle is moved from slow to fast, it can have detrimental effects on the planet.

2 Which of the following selections from the article BEST shows why all living things rely on carbon?

(A) We need carbon, but that need is also connected with one of our most serious problems: global climate change.

(B) Carbon is the fourth most abundant element in the universe. Most of Earth’s carbon — about 65,500 billion metric tons — is stored in rocks.

(C) The bonds in the long carbon chains contain a lot of energy. When the chains break apart, the stored energy is released.

(D) During the spring, when plants begin growing again, concentrations drop. It is as if the Earth is literally breathing.

3 Which option provides an accurate and objective summary of the article?

(A) Carbon is released and absorbed through slow and fast carbon cycles. The slow cycle happens over hundreds of millions of years and regulates the Earth's temperature. However, during the short carbon cycle, temperatures on earth can fluctuate. Many things can influence these cycles.

(B) The fast and slow carbon cycles are processes that regulate the amount of carbon in the atmosphere. The amount of carbon in the atmosphere influences the temperature of the Earth. Human irresponsibility has caused serious problems for our climate.

(C) The slow carbon process is the process by which acid rain breaks down rocks, which are then carried to the ocean and deposited on the ocean floor until the carbon is released again in a volcanic eruption. The fast carbon cycle is the way that living things release and absorb carbon from the environment.

(D) Carbon is essential to life on Earth, but an imbalance of carbon in the atmosphere can have effects on the Earth's climate. Carbon is absorbed, released and balanced by the slow and fast carbon cycles. Human activity has disrupted these carbon cycles.

4 Which of the following sentences from the article BEST develops a central idea?

(A) We are made of carbon, we eat carbon, and our civilizations — our economies, our homes, our means of transport — are built on carbon.

(B) Left undisturbed, the fast and slow carbon cycles maintain a relatively steady concentration of carbon in the atmosphere, land, plants and ocean.

(C) Humans are currently emitting just under a billion tons of carbon into the atmosphere per year through land use changes.

(D) By burning coal, oil and natural gas, we accelerate the process, releasing vast amounts of carbon that took millions of years to accumulate into the atmosphere every year