



## CARBON CYCLE GAME

### Reservoirs and rolls

This game should be played by small groups of students: at least two (2), and as many as six (6). Each student should be issued one die, so that there are the same number of dice as students in each “session” of the game. (Multiple sessions can be run simultaneously in the same classroom.)

Each session of the game should work like this:

- Each student rolls their die to see who goes first. Highest score is first roll, and then go clockwise from there.
- Each student rolls their die again. This roll determines in which reservoir they begin their journey.

If they roll a 1, they begin in “vegetation and soils.”

If they roll a 2, they begin in “crust.”

If they roll a 3, they begin in “mantle.”

If they roll a 4, they begin in “oceans.”

If they roll a 5, they begin in “atmosphere.”

If they roll a 6, they begin in “fossil fuels.”

- Now the game begins. Each player takes a turn in order. First they roll their die, and then depending on the number they roll, they read off the accompanying story (1-5 sentences) on the appropriate sheet. *For instance, if a student starts in “crust” and rolls a “3,” the student reads the story that begins with, “Melting at depth due to nearby intrusion...”* The other students listen to the story as read aloud, and comment on it as appropriate. Each story concludes by directing the student to the next reservoir in their journey. Then it is the next student’s turn.
- Keep playing until each student has rolled his or her die 6 times (six turns) and read 6 corresponding stories, or until the instructor says the game is over.



## VEGETATION & SOILS



Roll a 1: A plant gets eaten by a giraffe; metabolized, and pooped out. The poop is gathered up within half an hour by a dung beetle, who rolls it into a ball and lays eggs on it before tucking it into an underground burrow. The rainy season comes early, and saturates the ground with water. The beetle grubs drown before they can eat the carbon in the dung. The dung becomes mixed into the soil. Go to crust.



Roll a 2: An oak tree grows, grows, and grows. Mistletoe seeds arrive on one of its branches in a splatter of bird poop. The mistletoe germinates and its rootlets penetrate the oak's upper branches, stealing nutrients. Its strength diminishing, the oak finds it harder and harder to combat the mistletoe, especially during periods of drought. Eventually, it dies and falls over. The oak's wood and leaves rot. Bacteria and fungi consume the dead plant over about ten years. Slowly, its carbon is oxidized to carbon dioxide. Go to atmosphere.



Roll a 3: A cypress tree grows for 120 years, then dies, and falls into a swamp. Though the swamp water exchanges oxygen with the air, more vegetation falls in than can be broken down by the available oxygen. The water acts as a preservative. The cypress tree's carbon is preserved in this anoxic environment and over time is compressed to form coal. Go to fossil fuels.



Roll a 4: Forest fire! A college student who has been smoking socially for a few years tosses a lit cigarette out a car window while driving through a park area with friends. The cigarette smolders on the roadside for a minute, until a gust of wind flares up, and the grass next door catches fire. Soon, the blaze covers 500 acres. Your plant catches fire and burns. Its carbon is quickly oxidized to carbon dioxide, releasing a tremendous amount of heat. Go to atmosphere.



Roll a 5: The plant gets eaten by a caterpillar. The caterpillar gets captured and paralyzed by a parasitic wasp, which lays an egg on it and stuffs it down a hole in the ground. The egg hatches, and the paralyzed caterpillar is eaten alive by a wasp larva, which saves the head and vital organs for last. The larva grows and metamorphoses into an adult wasp. The wasp is eaten by a frog, which is then eaten by a heron. The heron dies and is consumed by fungi in the soil. The fungi release the heron's carbon as carbon dioxide. Go to atmosphere.



Roll a 6: A hurricane pours down rain for a day and a half. This softens the soil in which a plant is rooted, and then knocks it over with a powerful gust of wind. The plant is washed downstream, floating on a stream's flood current. Tributaries join to make a river, and the river flows out to sea. The tree decomposes and is consumed by bacteria and plankton in the upper water. Eventually, waterlogged, it sinks to the bottom. Go to ocean.



## CRUST



Roll a 1: Uplift and weathering of limestone. Rain drops falling through the atmosphere absorb a bit of carbon dioxide, making a small amount of carbonic acid. Calcite in coral skeletons in exposed limestone reacts with carbonic acid in rainwater, and is dissolved in runoff. The resulting bicarbonate ions are washed downstream. Go to ocean.



Roll a 2: Uplift and weathering of granite. Rain drops falling through the atmosphere absorb a bit of carbon dioxide, making a small amount of carbonic acid. The potassium feldspar in the granite reacts with the carbonic acid in rainwater to produce kaolinite clay, silica, and bicarbonate ions in solution. Bicarbonate ions are washed downstream, into rivers, then to bays, then to the open sea. Go to ocean.



Roll a 3: Melting at depth due to nearby intrusion of felsic magma. Assimilation of carbon-rich source rocks into the magma. Cooling and crystallization of the magma results in the growth of graphite crystals. The graphite-containing granite is uplifted to the surface. It is mined by people, and used in the construction of pencils. A student studying the carbon cycle uses the pencil to take notes, and the student succeeds in earning their degree. Their old notes get placed in the recycling bin after graduation, but before the recycling collection truck comes, the school catches fire and burns down. The carbon oxidizes. Go to atmosphere.



Roll a 4: Metamorphism liberates carbon from the rock, and extracts it in hydrothermal fluids, escaping at high pressure through a network of fractures in the rock. The hydrothermal fluids carry the carbon-rich fluids several kilometers through the crust to form veins of graphite. Go to crust.



Roll a 5: Rain drops falling through the atmosphere absorb a bit of carbon dioxide, making a small amount of carbonic acid. Infiltration of this slightly acidic rainwater into the ground dissolves marble, opening a wider and wider subterranean passage. As this cave expands in size, calcium and bicarbonate ions are flushed out, and carried to the surface at an emerging spring. There, travertine is deposited. The carbon dioxide exsolves from the groundwater solution and mixes with the air. Go to atmosphere.



Roll a 6: Subduction of old oceanic crust topped with a veneer of deep ocean sediments. Though some of the sediments are scraped off at the trench to form an accretionary wedge, about half continue their journey downward, to the beat of large earthquakes. They become mixed into the lower mantle. Go to mantle.



## MANTLE



Roll a 1: Metamorphism of subducted carbon to form diamond. The diamond is caught in down-welling mantle. Travels toward the core-mantle boundary for 50 million years. Go to [mantle](#).



Roll a 2: Metamorphism to diamond. The diamond is caught in up-welling mantle. Sudden depressurization initiates a flow of ultramafic magma toward the surface. The magma pierces the crust-mantle boundary and gurgles upward at rates of 30 meters per second. The intrusion expands as it reaches lower and lower confining pressures, causing the magma body to bulge outward into a carrot-like shape. At the surface it explodes in a massive shower of ultramafic rock peppered with diamonds. Go to [crust](#).



Roll a 3: Water leaked from a subducting plate attracts some mantle carbon. It triggers partial melting in the overlying mantle, producing a basaltic magma and an olivine-rich solid residue. The watery basalt rises upward due to its low density relative to the rocks around it. It hits the base of the overlying continental crust and pools there, transferring heat to the overlying felsic rock material. This heat transfer causes crystallization of the basalt and partial melting of the overlying crust, producing an intermediate-composition magma, which rises to erupt as andesite in a continental volcanic arc. As the andesitic lava erupts, it degases and releases carbon dioxide. Go to [atmosphere](#).



Roll a 4: Rising warm mantle decompresses, and begins to melt beneath an oceanic ridge. The mafic melt draws the carbon out of the surrounding rock and brings it up to shallower depths still. Decompression causes gases dissolved in the magma to exsolve; bubbles form vesicles, and the gas, so close to freedom, is instead trapped as a vesicle in the basalt. Go to [crust](#).



Roll a 6: Subduction brings ocean-bottom organic shale deep into the mantle, where it is metamorphosed to diamond but keeps sinking, all the way to the core-mantle boundary. The journey takes 26 million years. There, in the D'' layer, it joins a growing pocket of melt that eventually is massive enough and buoyant enough to begin rising to the surface as a plume. When the plume hits the base of the lithosphere 63 million years later, it triggers massive flood basalt eruptions. These flood basalts build an oceanic plateau on the seafloor, and that plateau is eventually buried in dead plankton that rain down from the sunlit waters above. Go to [fossil fuels](#).



Roll a 6: Fluid flow through the basaltic crust interacts with fluids released by rising (decompressing) mantle, and mixes into a hot, high-pressure cocktail. This fluid chemically reacts with the crust as it passes upward again, and is suddenly spewed out as a vigorous dark cloud at the bottom of the sea, a black smoker. Go to [ocean](#).



## OCEAN



Roll a 1: Deposition on seafloor in low-oxygen water as carbon rich mud. Lithification to black shale. Shale is scraped off a subducting plate of oceanic lithosphere as part of an accretionary wedge. Over time, subduction ceases and the accretionary wedge is uplifted. The shale crops out on the coast of a continent, where it is weathered by the waves. Fragments of shale are broken off as new sediments. These fragments are deposited as clasts within a new conglomerate. Go to crust.



Roll a 2: Incorporation into skeletal material of a coccolithophore shell. Upon its death, the coccolithophore falls to the ocean floor. Below the carbonate compensation depth, where the pressure is high and the temperature is cold, the calcite in its shell dissolves back into the water. Go to ocean.



Roll a 3: Incorporation into skeletal material of a coccolithophore shell. Eaten by zooplankton, which is eaten by krill, which is eaten by a sardine, which is eaten by a seagull, which goes on a migration inland in search of grasshoppers, but dies of exhaustion. Its body decays and is mixed by worms and grubs into the soil. Plants grow better in this fertile ground. Go to vegetation and soils.



Roll a 4: Burrowing worms stir up organic material in seafloor sediments. These worms are eaten by a pelagic crab, which is eaten by a squid, which is eaten by a glowing anglerfish, which chokes to death and falls to the seafloor. Its corpse is buried in mud. The mud is warmed up and the carbon in it reacts to form kerogen, and then oil. Go to fossil fuels.



Roll a 5: Bicarbonate ion dissolved in the ocean is brought up to the surface of the sea, where it meets the atmosphere. Carbon dioxide is released to the air. The rising bubble of carbon dioxide tickles the belly of a floating seagull before it hits the surface and pops. Go to atmosphere.



Roll a 6: Carbon dissolved in the seawater is pulled out by photosynthesizing diatoms. The diatom dies, and falls to the seafloor, where it is decomposed by methanogenic bacteria. The methane is released into the deep sea sediments, where it is incorporated into the growth of a mass of ice-like methane clathrate. Go to fossil fuels.



## ATMOSPHERE



Roll a 1: Photosynthesis in a plant pulls carbon dioxide from the air and bonds it to water (transported upward from the plant's roots). The resulting sugar molecule is stored in the plant's tissues. Go to [vegetation and soils](#).



Roll a 2: Convection of rising warm air and sinking cold air brings a carbon dioxide molecule down to the surface of the ocean. There, it dissolves into the shallow, warm ocean near the Bahamas. Go to [ocean](#).



Roll a 3: Photosynthesis by a stalk of wheat in Kansas extracts carbon dioxide from the air. The carbon dioxide is bonded to water that was sprayed onto the fields after being pumped up from the High Plains Aquifer. Combined, a molecule of sugar is produced. The wheat containing this sugar is harvested by a combine and stored in a silo for a week and a half. It is loaded onto a train and shipped to St. Louis, Missouri, where it is purchased by a brewery and mashed and fermented into beer. The beer is sold to a distributor, who sells it to a convenience store near a college campus. A student buys the beer to celebrate doing exceptionally well on a science exam. The student drinks the beer and metabolizes the alcohol. The student burps and exhales carbon dioxide. Go to [atmosphere](#).



Roll a 4: Methane is a powerful greenhouse gas, but very reactive. Oxidation of methane in the air produces carbon dioxide. Carbon dioxide is a greenhouse gas of less potency, but it lasts for much longer in the atmosphere. Go to [atmosphere](#).



Roll a 5: Rain falls from a cloud. Carbon dioxide diffuses into the raindrops, dissociating and forming carbonic acid. This acid rains on an outcrop of granite. Go to [crust](#).



Roll a 6: Nitrogen-14 high in the atmosphere, somewhere above Antarctica, is bombarded by cosmic rays, causing it to spall off a proton and convert to carbon-14. This carbon-14 quickly bonds with some of the 21% of the atmosphere that is free oxygen, and becomes incorporated into a "heavy" carbon dioxide molecule. Carbon-14's is radioactive. Its half-life is 5730 years, so its days are numbered. Go to [atmosphere](#).



## FOSSIL FUELS



Roll a 1: Buried sedimentary rocks rich in organic carbon are heated to around 100°C, causing the organic material to react and form kerogen and then oil. The oil leaves its source rocks because it is more buoyant than the surrounding water, and it rises to the surface at the future site of Los Angeles, where it traps unwary mammoths, ground sloths, and dire wolves. In the sun and air, the oil gets gummy and becomes tar, and is eventually oxidized to carbon dioxide. Go to [atmosphere](#).



Roll a 2: Deep ocean shale deposits are full of the undecayed bodies of billions of phytoplankton. When warmed to about the same temperature as a fresh cup of coffee, chemical reactions take place and produce oil and natural gas. These flow through pore spaces in the rock until their progress is stopped by an anticline capped by an impermeable layer of shale. Later, geologists deduce the anticline's presence, and encourage an oil company to drill a well there. The oil is extracted, refined to make gasoline, and sold to various other companies, who sell it to consumers, who use it to drive to the hospital, to school, and to the county fair. Burning the gasoline oxidizes carbon to produce carbon dioxide. Go to [atmosphere](#).



Roll a 3: Plant matter deposited in a swamp is buried under additional sedimentary layers of shale, sandstone, conglomerate, and volcanic ash. The weight of these overlying strata compress the plant matter into low-grade coal (lignite) and then eventually into bituminous coal. The coal remains undiscovered by humans, and stays underground for millions of years. Go to [crust](#).



Roll a 4: pump well Deep ocean shale deposits are full of the undecayed bodies of billions of phytoplankton. When warmed to about 100°C deep underground, chemical reactions take place and produce oil and natural gas. The natural gas is trapped in its shale source rock, but the invention of fracking allows geo-engineers to shatter the shale by injecting fluids and sand, and the natural gas flows through the new fractures to collection pipes. The gas is burned to warm homes in Minnesota during the winter, producing carbon dioxide. Go to [atmosphere](#).



Roll a 5: Plant matter deposited in a swamp is buried under additional sedimentary layers of shale, sandstone, conglomerate, and volcanic ash. The weight of these overlying strata compress the plant matter into bituminous coal. The coal is discovered by humans in Wyoming, who strip-mine it, and ship it by rail to Georgia, to be burned in a power plant. The energy from the coal powers Atlanta's electricity for 30 seconds. The carbon combines with oxygen to produce carbon dioxide, which is expelled through the power plant's tall smokestacks. Go to [atmosphere](#).



Roll a 6: Buried marine sedimentary rocks rich in organic carbon are heated to around 80°C, causing the organic material to react and form kerogen. The sludgelike kerogen is viscous and resists flow. Engineers working for an oil company figure out a way to pump hot water underground to extract the kerogen, which can then be refined at the surface to make jet fuel. An airplane burns the fuel on a flight from San Francisco to New York. Go to [atmosphere](#).