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The Carbon Cycle Interactive module is a virtual lab that uses a robust model of the carbon cycle. This virtual lab models how carbon circulates through the atmosphere, biosphere, oceans, and the Earth’s crust. In this activity, you will be altering the atmospheric CO2 levels.  INSTRUCTIONS:   1. Go to <https://www.learner.org/courses/envsci/interactives/carbon/> . 2. Read the **overview** paragraph and answer questions 1 and 2. 3. Click on the “OPEN SIMULATOR” icon. 4. Run the default simulation and the indicated 3 additional test simulations with the parameters set to those that are given in the table. (the 3rd simulation allows you to choose the value of your variables). 5. Notice that most of your data can be found by placing your cursor over points of interest in the generated graph. You will have to click RUN SIMULATION a DECADE several times in order to get some of these data points. You will also have to repeat the simulation several times to gather the needed data. You will need to click RESET to start the simulation over again. There is a tutorial on the website for more helpful information.   QUESTIONS:   1. What does the Overview section of the virtual lab say about the CO2 levels between 1850 and 2015? 2. How are ancient CO2 levels measured? 3. When we run the simulations, explain what is happening at the highest point of the graph. 4. After the fossil fuels are exhausted, explain how dissolved CO2 levels change between the time the fossil fuels run out and the time when the amount of dissolved carbon dioxide in the deep ocean no longer changes. 5. What is the effect of high CO2 levels in the deep ocean? 6. After the fossil fuels are exhausted, explain how the atmospheric CO2 levels change between the time the fossil fuels run out and the time when the atmospheric level of CO2 no longer changes. 7. Explain how excess CO2 levels affect terrestrial plant CO2 levels change between the time the fossil fuels run out and the time when the terrestrial plant level of CO2 no longer changes. 8. After the fossil fuels are exhausted, explain how the soil CO2 levels change between the time the fossil fuels run out and the time when the soil level of CO2 no longer changes. 9. What is the effect of high CO2 levels in the atmosphere? 10. What is the effect of high CO2 levels in terrestrial plants? 11. What is the effect of high CO2 levels in the soil? 12. What does ppm mean? 13. What does GT mean?  DATA TABLE  |  |  |  |  |  | | --- | --- | --- | --- | --- | | Parameter | DEFAULT  Parameter values | Simulation 1 | Simulation 2 | Simulation 3 | | **Year (considered)** | 2010 | 2010 | 2010 | 2010 | | **Fossil Fuel Use (% change per year)** | 2% increase | -2% increase | 2% increase | Your choice | | **Net deforestation rate per year** | 1 GT | 1GT | 0 GT | Your choice | | **Resulting Outcome** | **Atmospheric CO2 (in ppm)** | Simulation 1 | Simulation 2 | Simulation 3 | | **Value for “NOW” year** | 390 ppm |  |  |  | | **Value for 1850** | 287 ppm |  |  |  | | **Value for 2100** | 936 ppm |  |  |  | | **Value for 2500 (must click RUN DECADE)** | 507 ppm |  |  |  | | **Value at highest point of graph** | 1355 |  |  |  | | **In what year was the highest CO2 levels observed** | 2120 |  |  |  | | **In what year do we run out of Oil and Gas?** | 2070 |  |  |  | | **In what year do we run out of Coal?** | 2120 |  |  |  |   You should now have some understanding of how carbon moves through the system, but you may be wondering about the mechanisms behind this flow. As you read through the following explanations, refer to your Data Table for Lesson 1 Step 2.  **Atmosphere:** combustion of carbon-based fuel combines carbon, C, and oxygen, O2, adding CO2 to the atmosphere. CO2is not a by-product of fossil fuel use; it's the direct product of the very reaction that releases the energy.  **Biosphere (Terrestrial Plants and Soil):** plants (biomass) inhale CO2 and exhale O2. When there's more CO2 available, biomass tends to breathe in more, and therefore grow more. Most scientists now believe that plants have a limited ability to increase their growth rate.  **Surface ocean:** The amount of gas dissolved in any liquid is proportional to the partial pressure of that gas in the vapor phase above the liquid (Henry's Law). As a result, if we increase the partial pressure of atmospheric CO2 (i.e. increase the concentration of CO2), then we force more CO2 gas to dissolve into the liquid. (In this case, the liquid is the ocean.) In addition to the CO2 dissolving into the liquid as a gas, CO2reacts with H2O and forms bicarbonate ions (HCO3-) and carbonate ions (CO3--). This combustion of fossil fuels results in an increase in dissolved surface ocean carbon and a decrease in pH.  **Deep ocean:** Ocean chemistry involving mineral precipitation, and biological activity, and ocean currents transport the carbon from the surface ocean to the deep ocean over long time-scales.  **Understanding CO2 Concentrations and Carbon Flux**  Typically, scientists talk about atmospheric carbon dioxide in terms of ppm (parts per million), but, when they are talking about CO2 being released into the atmosphere, they refer to it as gigatonnes of carbon (Gt C). Although each of these units are appropriate for the data they are measuring, the relationship between them is not intuitive.  Measuring the concentration of CO2 in ppm denotes that, for every million parts of air, there is a given number of parts of CO2. This can be calculated as a mass fraction, a mole fraction or a volume fraction. For ideal gases, mole and volume fractions are equivalent, so ppm concentrations are calculated using either one of these two measures.  Also visit <https://www.learner.org/courses/envsci/unit/pdfs/unit11.pdf>  4. Biogeochemical Cycling in Ecosystems  Along with energy, water and several other chemical elements cycle through ecosystems and influence the rates at which organisms grow and reproduce. About 10 major nutrients and six trace nutrients are essential to all animals and plants, while others play important roles for selected species (footnote 3). The most important biogeochemical cycles affecting ecosystem health are the water, carbon, nitrogen, and phosphorus cycles. As noted earlier, most of the Earth's area that is covered by water is ocean. In terms of volume, the oceans dominate further still: nearly all of Earth's water inventory is contained in the oceans (about 97 percent) or in ice caps and glaciers (about 2 percent), with the rest divided among groundwater, lakes, rivers, streams, soils, and the atmosphere. In addition, water moves very quickly through land ecosystems. These two factors mean that water's residence time in land ecosystems is generally short, on average one or two months as soil moisture, weeks or months in shallow groundwater, or up to six months as snow cover. But land ecosystems process a lot of water: almost two-thirds of the water that falls on land as precipitation annually is transpired back into the atmosphere by plants, with the rest flowing into rivers and then to the oceans. Because cycling of water is central to the functioning of land ecosystems, changes that affect the hydrologic cycle are likely to have significant impacts on land ecosystems. (Global water cycling is discussed in more detail in Unit 8, "Water Resources.") Both land and ocean ecosystems are important sinks for carbon, which is taken up by plants and algae during photosynthesis and fixed as plant tissue.  Carbon cycles relatively quickly through land and surface-ocean ecosystems, but may remain locked up in the deep oceans or in sediments for thousands of years. The average residence time that a molecule of carbon spends in a terrestrial ecosystem is about 17.5 years, although this varies widely depending on the type of ecosystem: carbon can be held in old-growth forests for hundreds of years, but its residence time in heavily grazed ecosystems where plants and soils are repeatedly turned over may be as short as a few months. Human activities, particularly fossil fuel combustion, emit significant amounts of carbon each year over and above the natural carbon cycle. Currently, human activities generate about 7 billion tons of carbon per year, of which 3 billion tons remain in the atmosphere. The balance is taken up in roughly equal proportions by oceans and land ecosystems. Identifying which ecosystems are absorbing this extra carbon and why this uptake is occurring are pressing questions for ecologists. Currently, it is not clear what mechanisms are responsible for high absorption of carbon by land ecosystems. One hypothesis suggests that higher atmospheric CO2 concentrations have increased the rates at which plants carry out photosynthesis (so-called CO2 fertilization), but this idea is controversial. Controlled experiments have shown that elevated CO2 levels are only likely to produce short-term increases in plant growth, because plants soon exhaust available supplies of important nutrients such as nitrogen and phosphorus that also are essential for growth. Nitrogen and phosphorus are two of the most essential mineral nutrients for all types of ecosystems and often limit growth if they are not available in sufficient quantities. (This is why the basic ingredients in plant fertilizer are nitrogen, phosphorus, and potassium, commonly abbreviated as NPK.) A slightly expanded version of the basic equation for photosynthesis shows how plants use energy from the sun to turn nutrients and carbon into organic compounds: CO2 + PO4 (phosphate) + NO3 (nitrate) + H2O → CH2O, P, N (organic tissue) + O2 Because atmospheric nitrogen (N2) is inert and cannot be used directly by most organisms, microorganisms that convert it into usable forms of nitrogen play central roles in the nitrogen cycle. So-called nitrogen-fixing bacteria and algae convert ammonia (NH4) in soils and surface waters into nitrites (NO2) and nitrates (NO3), which in turn are taken up by plants. Some of these bacteria live in mutualistic relationships on the roots of plants, mainly legumes (peas and beans), and provide nitrate directly to the plants; farmers often plant these crops to restore nitrogen to depleted soils. At the back end of the cycle, decomposers break down dead organisms and wastes, converting organic materials to inorganic nutrients. Other bacteria carry out denitrification, breaking down nitrate to gain oxygen and returning gaseous nitrogen to the atmosphere (Fig. 10). Figure 10. The nitrogen cycle © U.S. Department of the Interior, National Park Service. Human activities, including fossil fuel combustion, cultivation of nitrogen-fixing crops, and rising use of nitrogen fertilizer, are altering the natural nitrogen cycle. Together these activities add roughly as much nitrogen to terrestrial ecosystems each year as the amount fixed by natural processes; in other words, anthropogenic inputs are doubling annual nitrogen fixation in land ecosystems. The main effect of this extra nitrogen is over-fertilization of aquatic ecosystems. Excess nitrogen promotes algal blooms, which then deplete oxygen from the water when the algae die and decompose (for more details, see Unit 8, "Water Resources"). Additionally, airborne nitrogen emissions from fossil fuel combustion promote the formation of ground-level ozone, particulate emissions, and acid rain (for more details, see Unit 11, "Atmospheric Pollution"). Phosphorus, the other major plant nutrient, does not have a gaseous phase like carbon or nitrogen. As a result, it cycles more slowly through the biosphere. Most phosphorus in soils occurs in forms that organisms cannot use directly, such as calcium and iron phosphate. Usable forms (mainly orthophosphate, or PO4) are produced mainly by decomposition of organic material, with a small contribution from weathering of rocks. The amount of phosphate available to plants depends on soil pH. At low pH, phosphorus binds tightly to clay particles and is transformed into relatively insoluble forms containing iron and aluminum. At high pH, it is lost to other inaccessible forms containing calcium. As a result, the highest concentrations of available phosphate occur at soil pH values between 6 and 7. Thus soil pH is an important factor affecting soil fertility. Excessive phosphorus can also contribute to over-fertilization and eutrophication of rivers and lakes. Human activities that increase phosphorus concentrations in natural ecosystems include fertilizer use, discharges from wastewater treatment plants, and use of phosphate detergents. | |