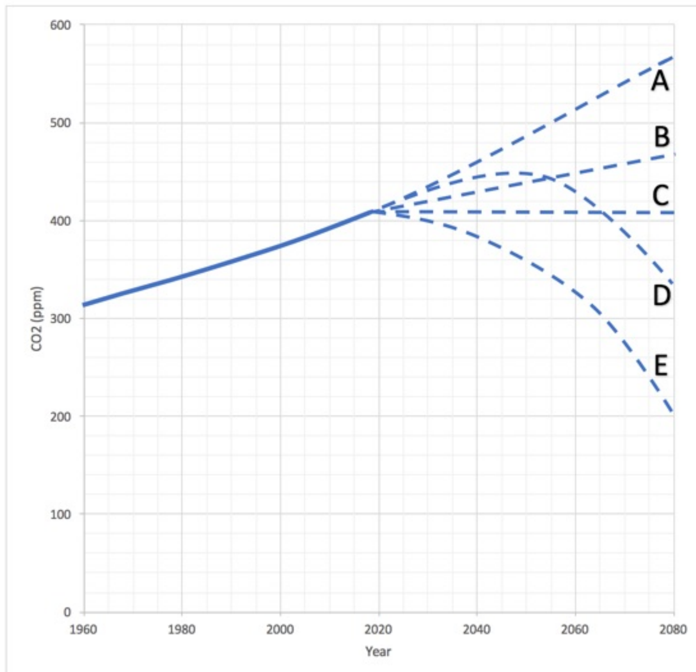
Name ______________________________ Teacher ________________ Date __________

What Would Happen If We Cut Fossil Fuel Use In Half?

Students in Mr. Yousef's class were learning about how carbon dioxide (CO_2) concentrations in the atmosphere change over time. Mr. Yousef showed students the graph below. The solid line shows global CO_2 concentrations between 1960 and 2016.

He asked students, suppose the world suddenly cut the use of fossil fuels (coal, diesel, gasoline, natural gas, etc.) in half and kept usage at that level. If nothing else changed, what would happen to atmospheric CO_2 concentrations over the next 50 years? Some students shared their ideas—the dotted lines on the graph below.



A: Jin, B: Latisha, C: Alana, D: Maya, E: Toby

Jin (A on the graph) thinks CO_2 concentrations will continue to increase at a similar rate because of other sources of CO_2 such as deforestation, population growth, and volcanoes.

Latisha (B) thinks CO_2 concentrations will continue to increase, but more slowly, because we will still be releasing CO_2 into the atmosphere, just not as much.

Alana (C) thinks that CO_2 concentrations will level off because there is less pollution.

Maya (D) thinks CO_2 concentrations will continue to increase for a while, then decrease as the CO_2 begins to dissipate in the atmosphere.

Toby (E) thinks CO_2 concentrations will decrease by half (to around 200ppm) because cutting emissions by 50% will lead to CO_2 concentrations decreasing by 50%.

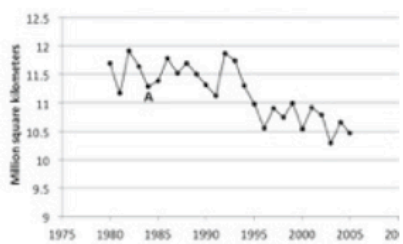
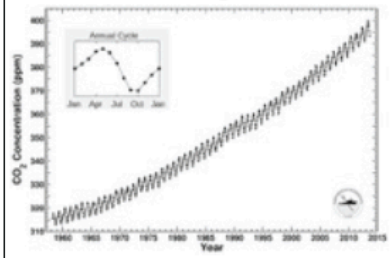
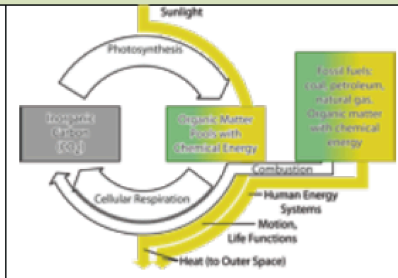
Who do you agree with and why do you think they have the best answer? It's ok to pick more than one person. Explain why you chose the answer(s) you did.

Interpreting and Responding to Students' Ideas

See *Using Big Idea Probes in Carbon TIME* for guidelines on how to implement this probe several times while teaching the Human Energy Systems (HES) unit. Two appropriate times to use this probe would be at the end of Lesson 4, and just before administering the unit posttest.

The central observations, patterns and models that form the focus of the HES unit are shown in the table below (also found in the Instructional Model document).

The Human Energy Systems Unit

Observations, Patterns, and Models for the *Human Energy Systems* Unit		
Arctic Sea Ice  	The Keeling Curve  	
Observations and patterns: Students use visualizations and graphs to investigate patterns of change in global climate-related data, including: • Arctic sea ice has declined erratically since 1975. • Global temperatures have risen about 1° Celsius since 1880. • Global sea levels have risen more than 20 cm since 1870. • Atmospheric CO_2 concentrations have increased from about 310 to 400 ppm since the late 1950s.	**Observations and patterns:** Students also use visualizations and graphs to investigate changes in atmospheric CO_2 concentrations. Key patterns include: • The annual cycle: CO_2 concentrations in the northern hemisphere decline every summer and rise every winter. • The long-term trend: Global CO_2 concentrations have increased from about 310 to 400 ppm since the late 1950s.	**Models (and Explanations):** Students explain carbon cycling and energy flow between carbon pools by connecting global, macroscopic, and atomic-molecular scales, and answering the Three Questions: • **Pools**: carbon atoms are found in CO_2, living organisms, soil organic carbon, oceans, and fossil fuels. • **Fluxes**: Changes in photosynthesis drive the annual cycle; combustion of fossil fuels drives the long-term trend. • **Energy**: CO_2 and other greenhouse gases cause climate change.

One focus of the HES unit is on how students use the observations, patterns, and models (explanations) above to make large-scale predictions about carbon cycling over time. A recurring data source in the unit is the Keeling Curve, which shows the concentration of atmospheric carbon dioxide in Mauna Loa, Hawaii from 1958 until the present. The long-term pattern evident in the Keeling Curve data is the accelerating increase in carbon dioxide concentration that has been caused by unbalanced fluxes in carbon cycling, which are the result of anthropogenic fossil fuel emissions.

Reasoning and making predictions about fluxes and pools is a sophisticated practice that requires individuals to coordinate understanding of observations, patterns and models. The *Big Idea Probe* developed for this unit, “What would happen if we cut fossil fuel use in half?” highlights some of the challenges that students encounter when they make predictions concerning carbon pools and fluxes. The student ideas presented in this probe came from interviews we conducted with college students. We used what we learned from the interviews to predict how students might answer the probe and to make recommendations for instruction that responds to common ideas.

Latisha’s answer is the most sophisticated. She recognizes that a flux is not the same as a pool. Even if we halve the amount of CO_2 emissions associated with fossil fuel combustion, we are still emitting CO_2 at a rate that will not be balanced by fluxes of carbon out of the atmosphere. This is because the creation of fossil fuels is a process that takes place over millions of years. Processes that move CO_2 from the atmosphere into biomass and ocean pools are limited and cannot move all of the CO_2 emitted by burning fossil fuels back out of the atmosphere every year. Thus, while halving emissions decreases the carbon flux from the fossil carbon pool into the atmosphere, the atmospheric pool will continue to increase, though at a reduced rate (less steep positive slope). Latisha's response reflects prediction practice at the level of quantitative modeling.

Jin's response reflects an intermediate level of practice. Like Latisha, Jin recognizes that fluxes and pools are not the same thing (i.e., even though the flux is decreasing the pool can still increase over time). In some senses, Jin is correct. For example, population increases and associated increases in things like raising livestock could lead to small increases in CO_2 emissions as a result of more cellular respiration. However, such changes would likely also be associated with increases in carbon emitting energy uses. In the introduction to the question, we hold other changes in fluxes constant by stating that "nothing else changed." Given the nothing else changed proviso, CO_2 concentration in the atmosphere should continue to increase, but at a less steep slope. Because she is fairly sophisticated in her prediction practice about carbon pools and fluxes, Jin could likely benefit from opportunities to interact with quantitative modeling simulations. See, for example, the Very, Very Simple Climate Model integrated into Activity 6.2 as well as (also from UCAR) the Climate Bathtub Model of Earth's Carbon Cycle and the version of the model showing Rising Then Falling Emissions.

Toby's response reflects a conflation of fluxes and pools (thinking that if we cut a flux in half the pool will also be cut in half). **We consider Toby's response to represent a somewhat lower, but still intermediate, level of practice.** While he is conflating pools and fluxes, he is still attempting to trace the carbon in a quantitative fashion. Like Jin, Toby could also benefit from some work with and discussion of models of carbon fluxes and pools. He may need some targeted scaffolding to help him develop reasoning about why changes in fluxes do not result in the same changes in pools.

Alana's and Maya's responses represent less sophisticated practice reflective of students who have not yet committed to tracing matter. Students who choose Alana's or Maya's response may hold ideas about Earth having natural tendencies to balance itself out. They may also think of pollution as something that is just "bad" for the environment, rather than thinking scientifically about carbon cycling and energy flow in Earth systems. Students who choose Alana's and/or Maya's responses could benefit from continuing to work with the Large Scale Three Questions to help them develop understanding of and commitment to the rules that atoms last forever, carbon cycles, and energy flows at all scales (including large scale) in Earth systems.