Carbon Cycle Introduction

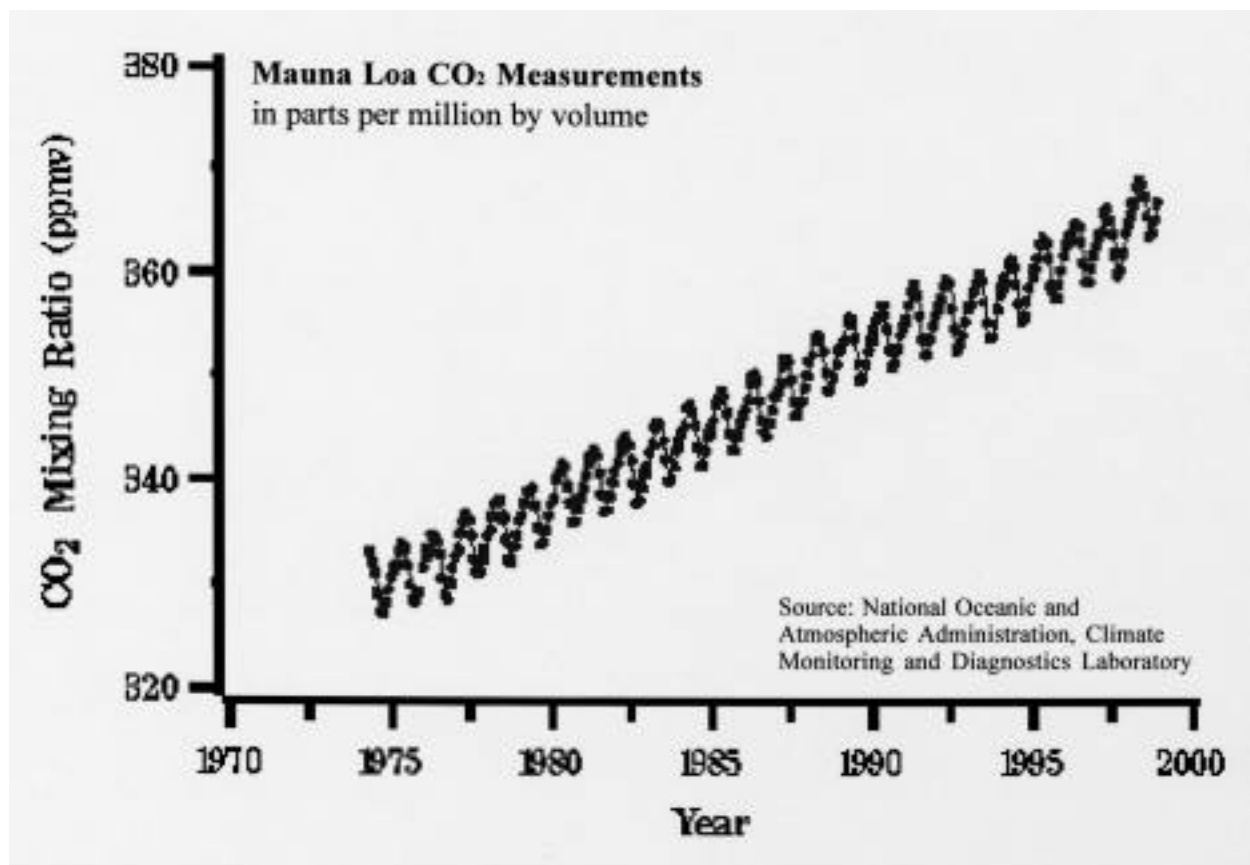**Carbon on Earth**
Life of earth is based on carbon. Living things acquire carbon from their environment - from air, water, soil, and rock and from other living things. Carbon moves in complex chemical and physical transfers from sources, or reservoirs, where carbon is released, to sinks, where carbon is taken up. This movement is the global carbon cycle. Earth's atmosphere, ocean, land, and living things can be both sources and sinks of carbon.

The processes of photosynthesis, respiration, death, and decomposition move carbon through the carbon cycle partly as carbon dioxide. In Earth's atmosphere, CO_2 is only about 0.03% by volume, but it is an important "greenhouse" gas. It traps in the lower atmosphere much of the heat radiated from the Earth's surface.

Carbon in the atmosphere
Since the late 1950s, scientists have regularly measured CO_2 in the atmosphere from observatories in Hawaii and Antarctica. CO_2 concentration rises and falls about the same amount each year due to seasonal changes in photosynthetic rates. Each year, however, the total amount of atmospheric CO_2 is greater than the year before. The upward trend of the curve on the graph below shows that CO_2 is steadily increasing in the atmosphere.

Mauna Loa CO_2 Measurements in parts per million by volume

Source: National Oceanic and Atmospheric Administration, Climate Monitoring and Diagnostics Laboratory

The recent increase of CO_2 in the atmosphere may be due to human activities. Widespread use of fossil fuel started in the early nineteenth century, with the Industrial Revolution. Combustion of coal, oil, natural gas, and peat releases carbon, mostly as CO_2. That carbon was stored as carbon compounds in rock for thousands or millions of years. Changes in land use, such as cutting forests to clear areas for agriculture, also release carbon. Forest renewal on old farms, however, takes carbon from the atmosphere.

CO2 effects

The future effect of increasing atmospheric CO_2 worries many people. More CO_2 should trap more heat, raising the temperature of the troposphere, the lowest layer of the atmosphere and the layer that people live in. People call this kind of overall increase in temperature "global warming". A temperature increase of a few degrees could have major consequences. On the other hand, recent scientific research suggests that a global temperature rise would precede an increase in atmospheric carbon. Whether global warming is occurring and what humans should do to cope with it are subjects of intense debate. Although people do not fully understand how Earth's climate operates and how it has changed through geologic time, they must make decisions for the future using the best current information available. Decisions are often based on the best computer models available.
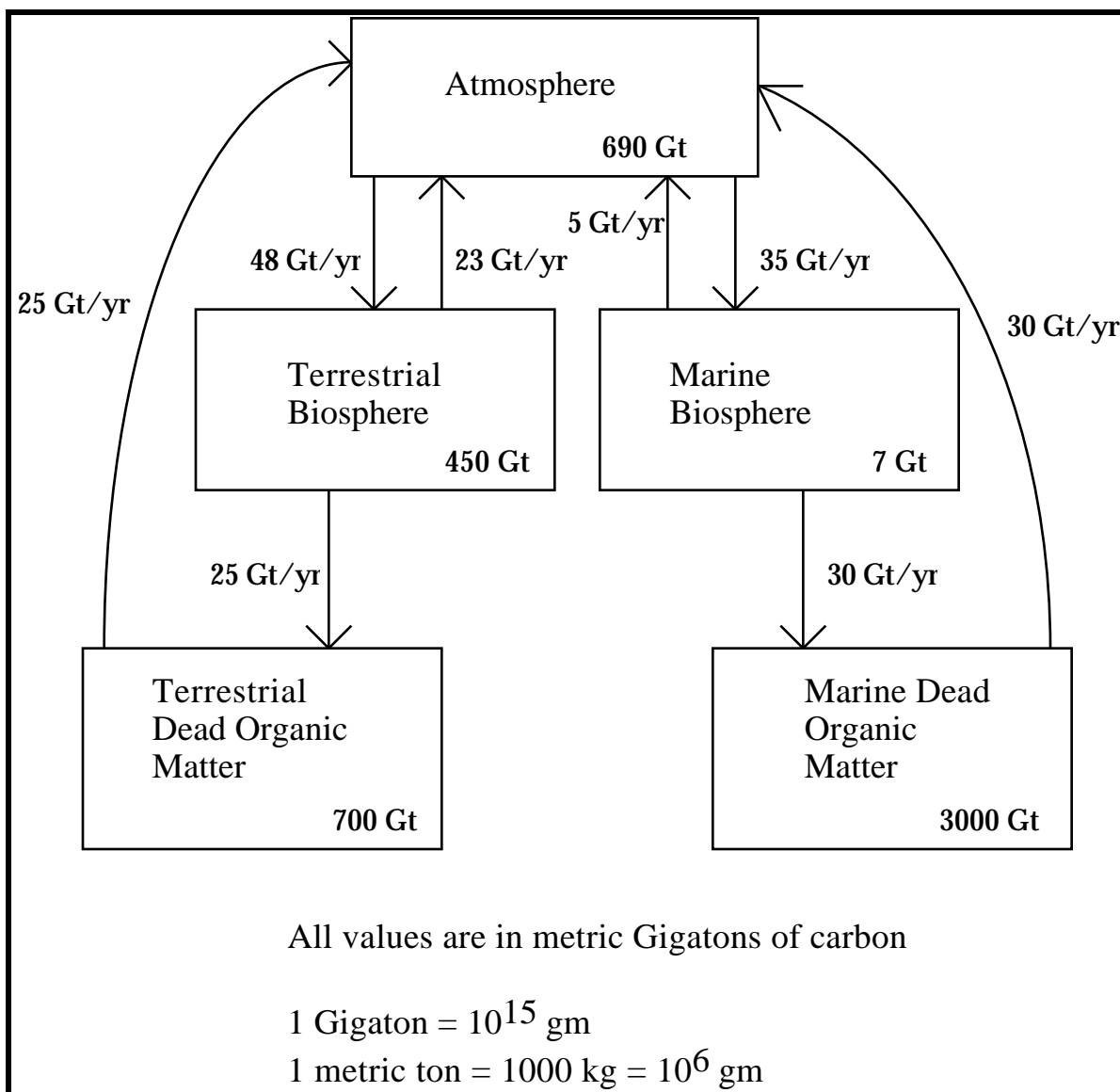
Modeling the carbon cycle

To organize information about parts of the Earth system and investigate relationships among the parts of the system, scientists use computers to simulate systems. With computer modeling software and the most accurate assumptions possible, current data and relationships can be linked to build a system model. The model may be run under different scenarios to try to show future states of the system. Scientists incorporate new data to improve the model so it more nearly reflects reality. One way to study a complex system is one part at a time. The carbon cycle is one part of the Earth system. Building a computer model of the carbon cycle will allow you to see the effects of disturbances to the cycle.

Carbon Cycle
Box Model

Carbon is constantly exchanged around the planet, taking a variety of forms through chemical and biological processes. The diagram below shows estimates of the numbers of metric Gigatons of carbon found in parts of the Earth system in the early 1970's. The boxes represent amounts of carbon in various forms and the arrows represent the rates at which the carbon is moved from one part of the system to another.

1. Beside each arrow, name the process being represented.
2. If each arrow represents a movement of carbon in metric Gigatons per year, calculate how much carbon will be in each box one year from now.

Atmosphere
690 Gt

5 Gt/yr

48 Gt/yr   23 Gt/yr   35 Gt/yr

25 Gt/yr   30 Gt/yr

Terrestrial Biosphere
450 Gt

Marine Biosphere
7 Gt

25 Gt/yr   30 Gt/yr

Terrestrial Dead Organic Matter
700 Gt

Marine Dead Organic Matter
3000 Gt

All values are in metric Gigatons of carbon

1 Gigaton = 10^{15} gm
1 metric ton = 1000 kg = 10^6 gm

Carbon Cycle Model
Student Guide

Introduction: By building a computer model of the carbon cycle, you will be able to see the effects of human disturbances, such as fossil fuel burning, on the carbon cycle. The boxes in the carbon cycle box model will be represented by stocks and the processes which move the carbon from one box to another will be represented by flows.

Part A: Building the Basic Model

1. **Double click** on the **STELLA** icon.

2. **Click** on the icon of the world ⊞ once. It should change to an x^2 .

3. The top bar looks like this:

4. **Click** on the stock icon ☐ and slide your pointer out into the open field and click again. A large stock should appear with the word **Noname 1** highlighted. **Type** the word **Atmosphere.**

5. Locate four more stocks on your screen, spreading them out on the screen and naming each one as shown on your carbon cycle diagram (**Terrestrial Biosphere, Marine Biosphere, Terr Dead Organic Matter** and **Mar Dead Organic Matter**).

6. To get rid of the question marks inside the stocks, **double-click** on **each** stock. In the window that appears,
   - Remove the **check mark** from the **Non-negative** box by **clicking** on it.
   - In the large text box, enter the appropriate number from the diagram, including the units in **{ }**.
        For example, **Initial(Atmosphere) = 690 {Gt}**.
   - **Click** on **OK** to close the window.

7. Click on the flow icon ⚲ . Slide your pointer inside the **Atmosphere** stock, **click and drag** toward the **Terrestrial Biosphere** stock. Since the two stocks are not in direct line with one another, you will want to make the flow bend at a right angle. To do that, hold down the **shift** key when you are ready for the turn. Then continue with the **drag** motion until the arrow just touches the stock and the stock becomes shaded. Let go of the mouse button. Name the flow **Terr Photosynthesis.**

8. Add flows for **Terr Respiration, Terr Death,** and **Terr Decomposition.**

9. Add four more flows for the marine side of the cycle and name the flows according to the process taking place.

10. Check your model against the diagram on the next page. Make any corrections needed.

11. Double-click on each flow and enter the appropriate number from the carbon cycle box model, including the units in **{ }**.

12. Your model should now have 5 stocks and 8 flows. Double check that the values entered match those from the box model.
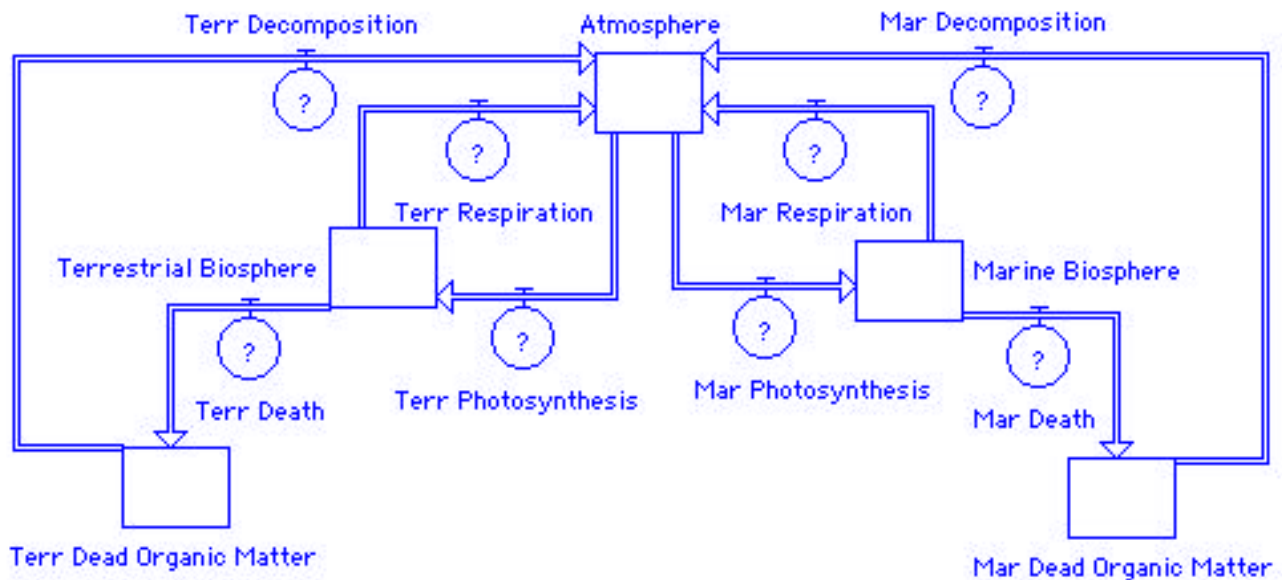

Part B: Setting up a Graph

13. Go back to the menu bar and **click** on the graph icon . Slide your mouse pointer to a clear spot in the window and **click** again.

14. To prevent the graph box from disappearing every time you run the model, you should pin down the graph window.
- Move your pointer to the horizontal bar at the top of the graph window.
- Drag the graph so it fits on the white space below the model.
- Click on the black circle (looks like a push pin) in the upper left-hand corner of the graph.

15. **Double-click** anywhere in this graph and a new window will open. In the top center of this window, you will see two boxes which look like this:
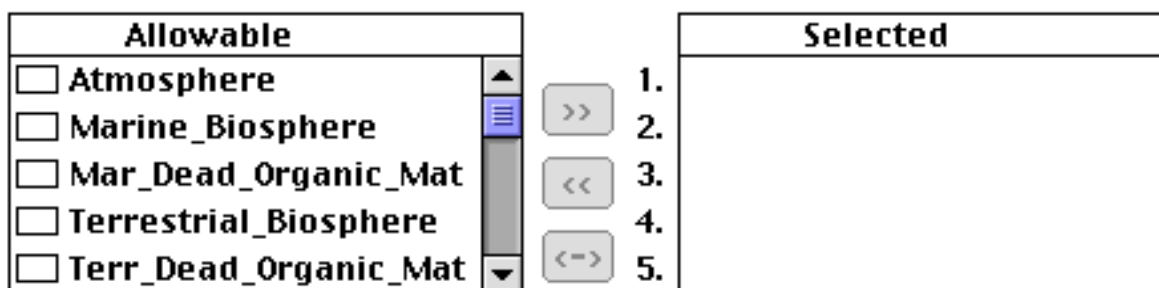
16. **Click** on the word **Atmosphere**, then click on the **>>** symbol. **Repeat** for **Marine_Biosphere** and **Terrestrial_Biosphere**. The boxes would now look like this:
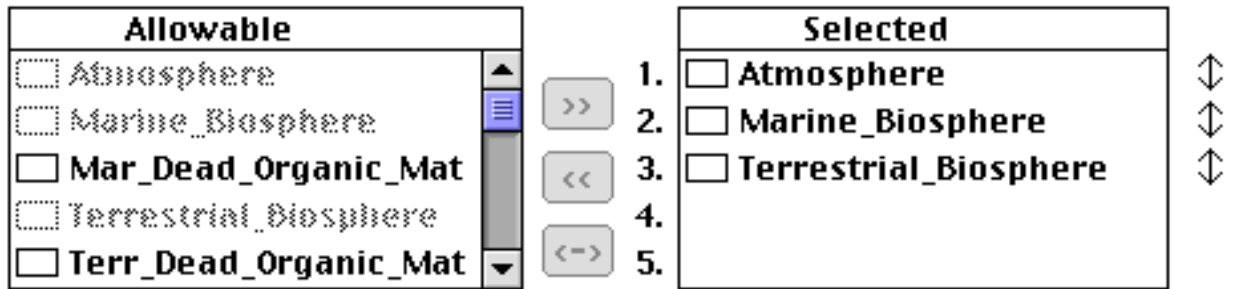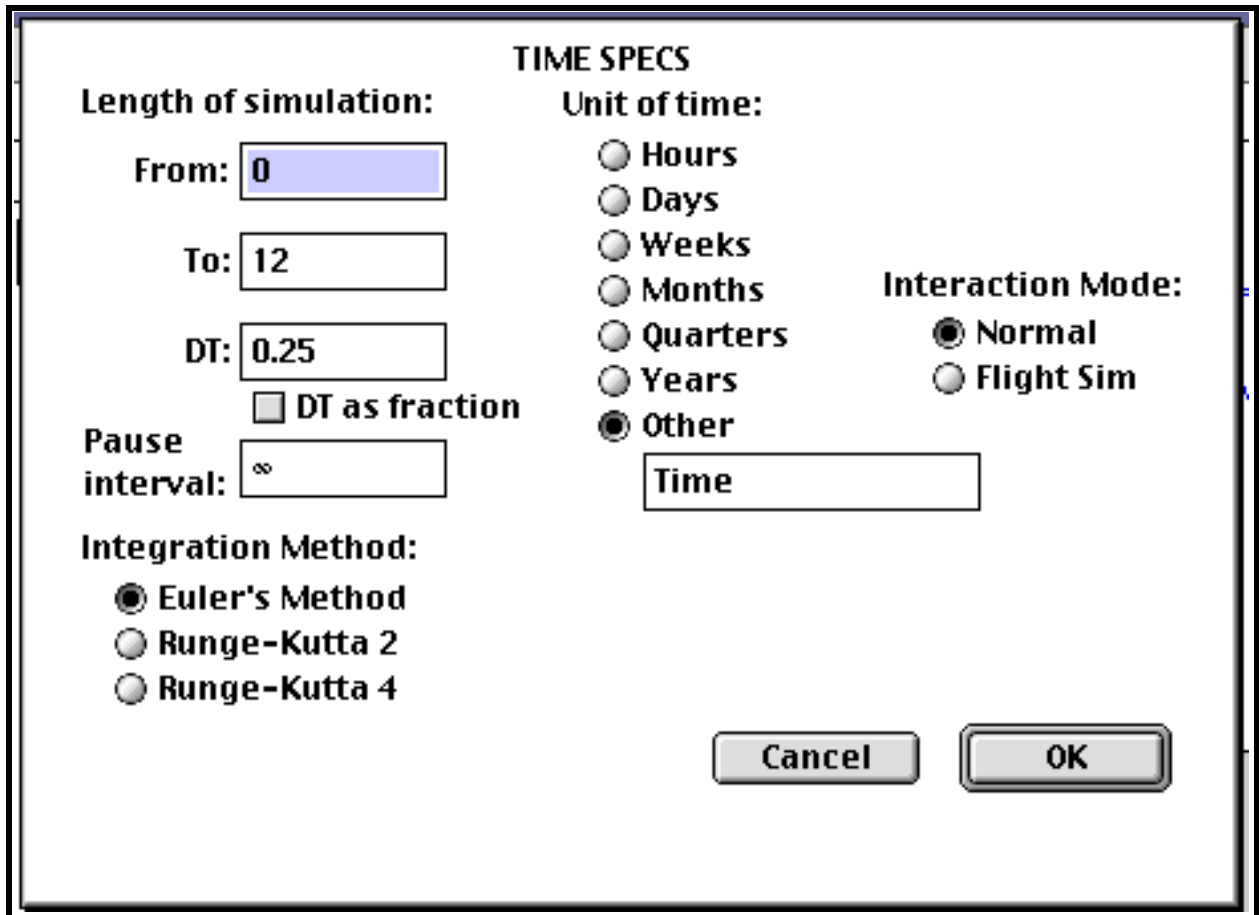
Click on **OK.**

17. You should be back at the graph, with the words **Atmosphere**, **Marine_Biosphere** and **Terrestrial_Biosphere** in different colors and keyed to different numbers (1,2,3) at the top of the graph.

Part C: Setting the Time Specs

18. Go to the **Run** menu and drag down to the **Time Specs...** option. You will see this window:

19. Change the length of the simulation to **100** by replacing the 12 with 100 and select **Years** as the unit of time. Click **OK**.

Part D: Running the Model

20. From the very top menu, **Click and hold** at the word **Run**, then without letting go of the mouse button, slide down to **Run** on the menu and release.

21. Three graph lines should form on the graph, each labeled 1, 2 or 3. Notice that there are also three different scales on the vertical axis, each keyed 1, 2, 3.

> **Q1.** Sketch the graph generated on the axes provided, labeling all parts.
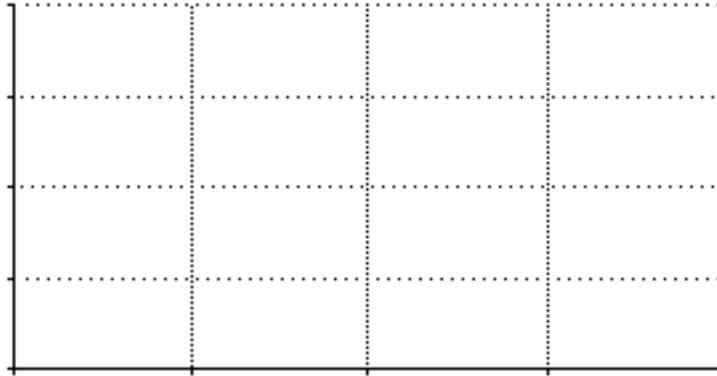
> **Q2.** Reading from the graph, record the equilibrium values for the stocks Atmosphere, Marine Biosphere and Terrestrial Biosphere.
>
> Atmosphere = _____   Marine Biosphere = _____   Terrestrial Biosphere = _____

22. Compare these results to the original box model. If the results do not match, there must be an error in your model. You may need to seek assistance from your teacher.

Part E: Modeling Disruptions to the Carbon Cycle

23. Your model shows the carbon cycle in a state of equilibrium. Scientists have determined that for the 1000 years prior to the Industrial Revolution (750 - 1750), carbon levels in the atmosphere remained relatively stable. Although there were fluctuations in the carbon levels from year to year, they stayed close to the same level overall. In the past 100 years, however, the carbon levels in the atmosphere have been rising steadily.

> **Q3.** What is missing from your model that might account for the modern day increase in atmospheric carbon?

Part F: Adding fossil fuel emissions

24. The increasing use of fossil fuels as an energy source has resulted in annual increases in the levels of carbon dioxide in the air. You will now add fossil fuels and their emissions to your model to see the impact on the carbon cycle. Current emissions from burning fossil fuels are estimated at about **5.5 Gt/yr** of carbon. Scientists estimate that the carbon-based fossil fuel - coal, oil, natural gas, and peat - available for future use contains approximately **10,000 Gt** of carbon. Put this information in your model by adding a new stock, **Fossil Fuel**, and a new flow, **Fossil Fuel Emissions** and entering the values given.

> **Q4.** Into which stock should the Fossil Fuel Emissions flow enter?

> **Q5.** Run the model and sketch the graph generated on the axes provided, labeling all parts.
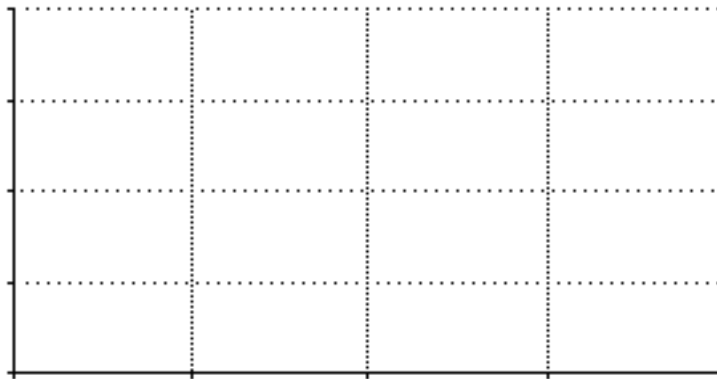
> **Q6.** Describe in full each curve on the graph.

> **Q7.** Your graph shows the carbon in the marine and terrestrial biospheres staying constant in spite of the increasing amounts of carbon in the atmosphere. Is this a reasonable result? Justify your answer.

During the rest of the activity, you will be keeping track of the amounts of carbon in the atmosphere, the marine biosphere and the terrestrial biosphere. In order to accurately record these amounts, you should create three numeric displays.

Part G. Using a Numeric Display
25. To create three numeric displays, go to the tool bar.

- **Click** on the numeric display icon: ⊟ . Slide your mouse pointer to a clear spot just above the pinned-down graph and **click** again.
- **Double-click** on the numeric display strip to see a window like the one below.
- **Double-click** on Atmosphere in the **Allowable** box to move it to the **Selected** box. Be sure that the **Retain Ending Value** and **Show Name** boxes are checked.
- **Click** on **OK**.
- Repeat the steps above for **Marine Biosphere** and **Terrestrial Biosphere.**
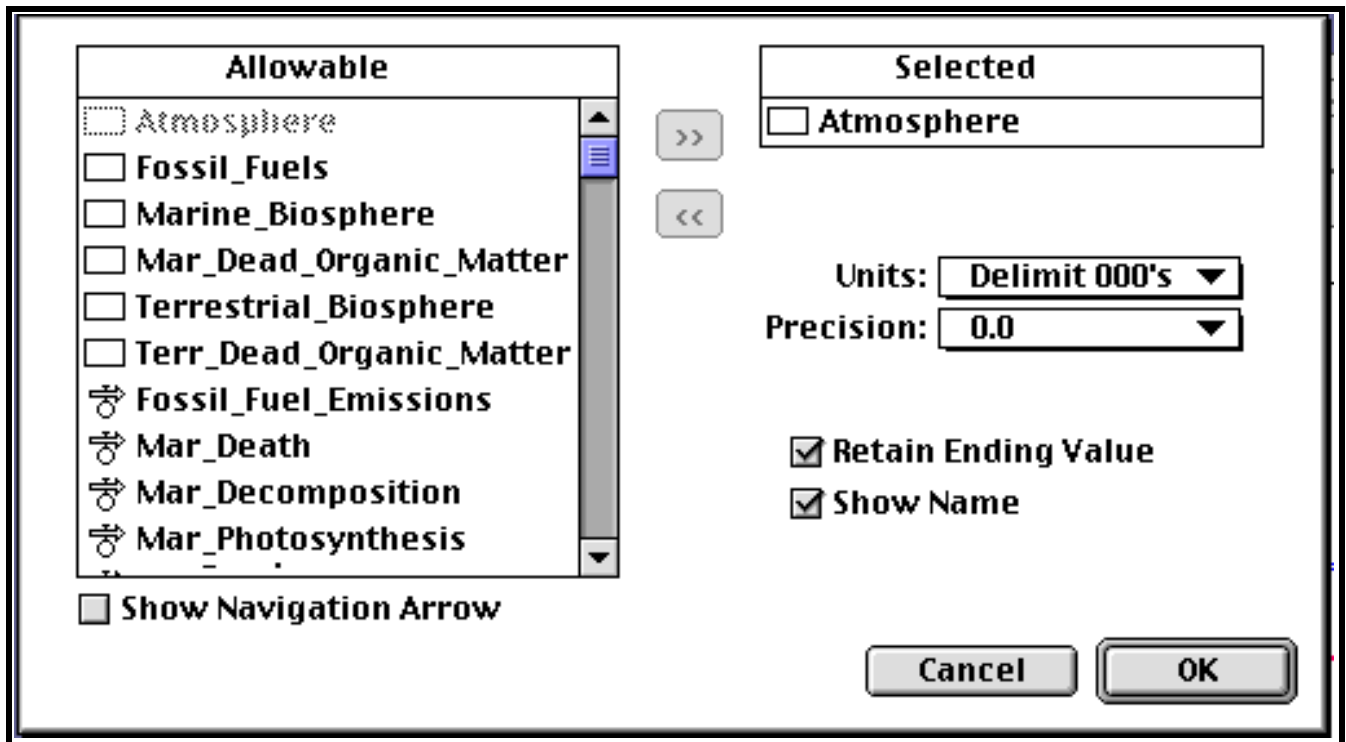
Q8. Reading from the numeric displays, record the final values for the stocks Atmosphere, Marine Biosphere and Terrestrial Biosphere.

Atmosphere = _____   Marine Biosphere = _____   Terrestrial Biosphere = _____

Q9. Data collected from the Mauna Loa Observatory in Hawaii shows atmospheric carbon increasing by approximately 14 percent during the time period from 1958 to 1993. If this trend were to continue, in 100 years there would be a 40 percent increase. Determine the percent increase in atmospheric carbon demonstrated by your model.

Q10. How would you explain the discrepancy between your model and the data collected at Mauna Loa?

Since you know that the marine and terrestrial biospheres respond to increases in atmospheric carbon dioxide by increasing their CO2 uptakes, you should be wondering why your model shows no increase in the amount of carbon in the marine and terrestrial biospheres. The reason is that the flows out of the atmosphere stock are always the same constant values that you put in from the measurements given in the carbon cycle box model. Although those measurements were valid in the 1970's, they could rise in later years. Your next step will be to show that the processes in the model respond to the amounts of carbon in the stocks from which they flow.

Q11. Which carbon cycle process(es) would you expect to be altered if Atmospheric carbon increased? How would they be altered?

Part G: Adding feedback

26. To show that terrestrial photosynthesis depends on the amount of carbon dioxide in the

atmosphere, **click and drag** a **connector** [ ] from the **Atmosphere** stock to the **Terrestrial Photosynthesis** flow, releasing the mouse button once the flow is shaded.

Proportions are often used to show that as one variable changes, others change similarly. For example, if the amount of carbon in Terrestrial_Photosynthesis is proportional to the amount of carbon in the Atmosphere, the equation is:

$$\frac{\textbf{Terrestrial\_Photosynthesis}}{\textbf{48}} = \frac{\textbf{Atmosphere}}{\textbf{690}}$$

The equation says that if the amount of atmospheric carbon rises above 690 Gt, terrestrial photosynthesis will increase proportionally. If the atmospheric amount falls below 690 Gt, photosynthesis will decrease proportionally.
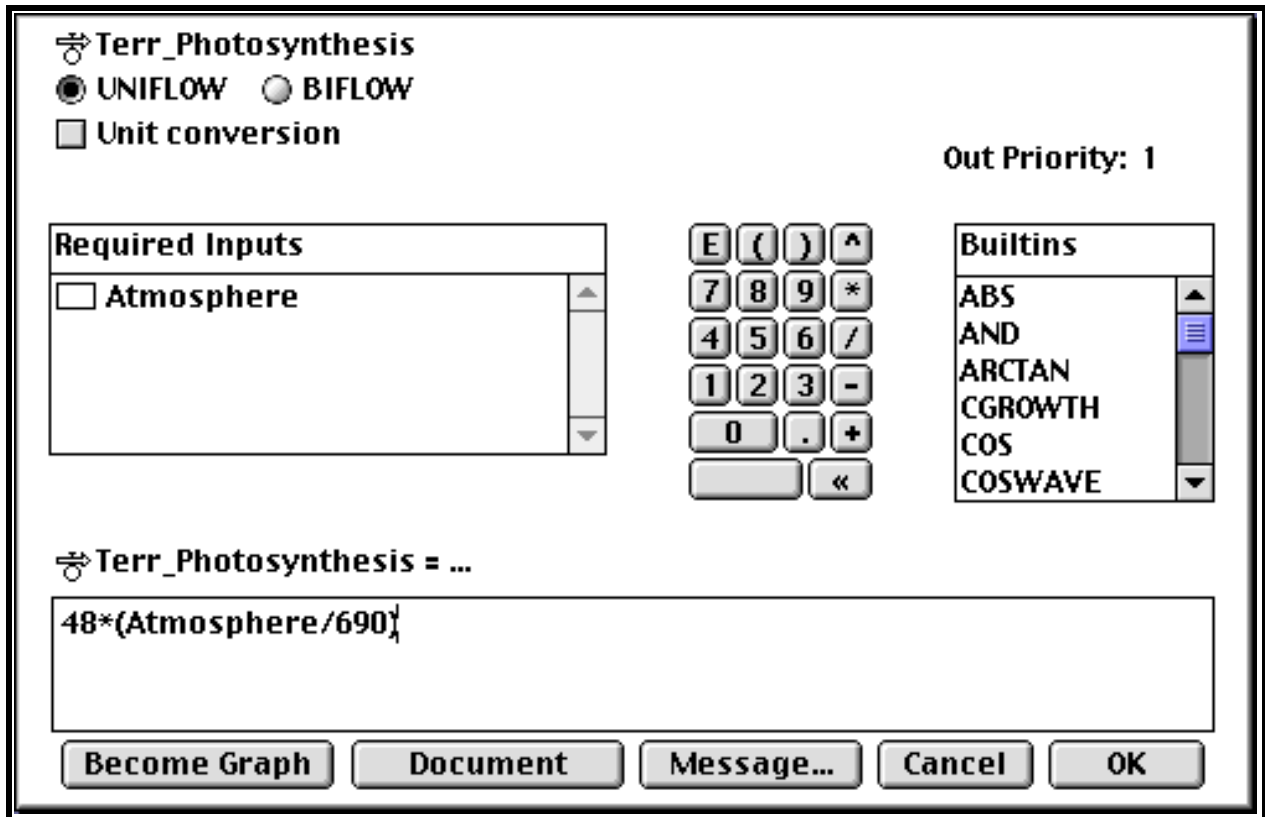
Solving for Terrestrial_Photosynthesis gives the equation

Terrestrial_Photosynthesis = 48 * Atmosphere/690

10

27. **Double-click** on the Terrestrial Photosynthesis flow. By clicking on the keypad and the **Required Inputs** box, change the equation box for **Terr Photosynthesis** so it reads:

   Terr_Photosynthesis = 48 * Atmosphere/690.

The window should look like this:

       Q12. You should create a similar connection for marine photosynthesis. Write the new equation for marine photosynthesis.

28. Run the model and observe the changes in the graph.

       Q13. Reading from the numeric displays, record the final values for the stocks Atmosphere, Marine Biosphere and Terrestrial Biosphere.

       Atmosphere = _____   Marine Biosphere = _____   Terrestrial Biosphere = _____

       Q14. You should have observed that the atmosphere value decreased from the previous run, but the marine biosphere and terrestrial biosphere values increased. Explain why that occurred.

Q15. If the terrestrial biosphere increases, then terrestrial respiration should also increase. Why would an increase be expected?

29. By now, you should recognize that feedback loops are required for all of the processes except fossil fuel emissions, which we are still considering as a constant rate. Add the feedback to the rest of the model.

30. **Warning**: pay close attention to the direction of the arrows so that the dependencies look like the diagram below. Also, pay close attention to the numbers you are using in the formulas.

31. Run the model and observe the changes in the graph.

Q16. Reading from the numeric displays, record the final values for the stocks Atmosphere, Marine Biosphere and Terrestrial Biosphere.
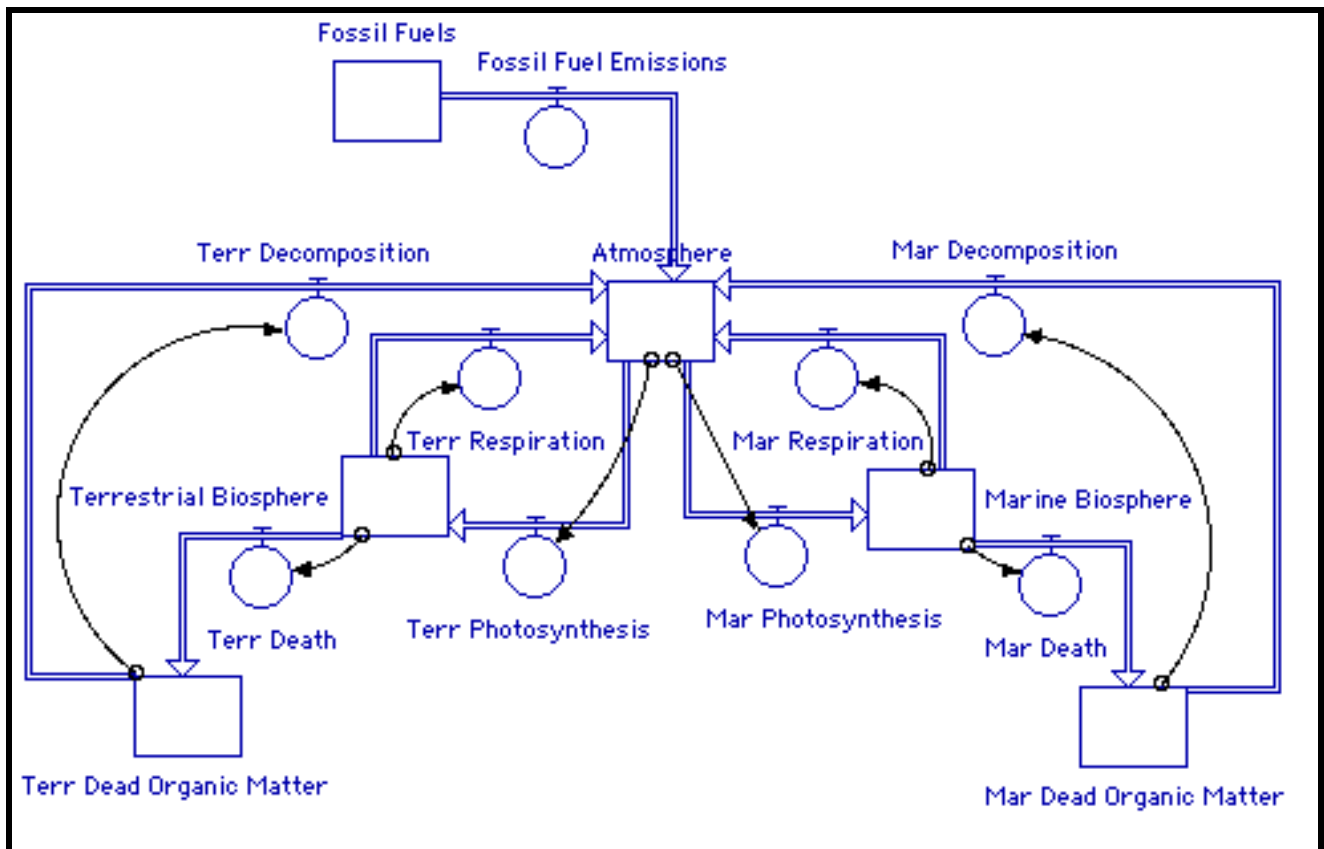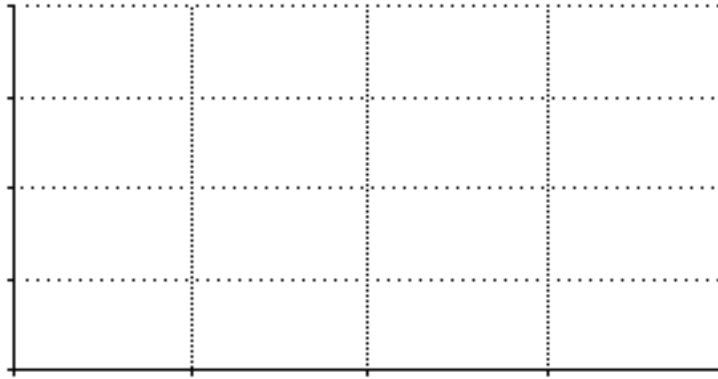
Atmosphere = _____   Marine Biosphere = _____   Terrestrial Biosphere = _____

Q17. Sketch the graph generated on the axes provided, labeling all parts.

Q18. Describe in full each curve on the graph.

Part H: Reducing fossil fuel emissions

The Kyoto Protocol, signed in November 1998, calls for an overall reduction of emissions of greenhouse gases. In the United States, the goal is to have emission levels ten years from now be 7 percent less than they were in 1990. Although greenhouse gases include methane and water vapor as well as carbon dioxide, you will only look at atmospheric carbon through your model. Since the data for the model represents carbon levels in the 1970's, suppose that the 100 years in your model represents the time period 1970 - 2070. Further suppose that you have been asked to determine the effect of a seven percent reduction in fossil fuel emissions on the atmospheric carbon.

32. Go to the **Run** menu and under the **Time Specs...** option, change **From: 1970** and **To: 2070** to make it easier to modify your model.

33. Since it is reasonable to assume that the United States will gradually reduce fossil fuel emissions to meet its goal, an input graph is the best way to model the reduction.

Part I: Creating an Input Graph

34. **Double-click** on the Fossil Fuel Emissions flow and enter **Time** in the equation box. Then click on **Become Graph**. Take note of the following:

Fossil_Fuel_Emissions is the dependent variable and Years is the independent variable. The scale on the x-axis goes from 1970 to 2070, and the scale on the y-axis goes from 0 to 100.
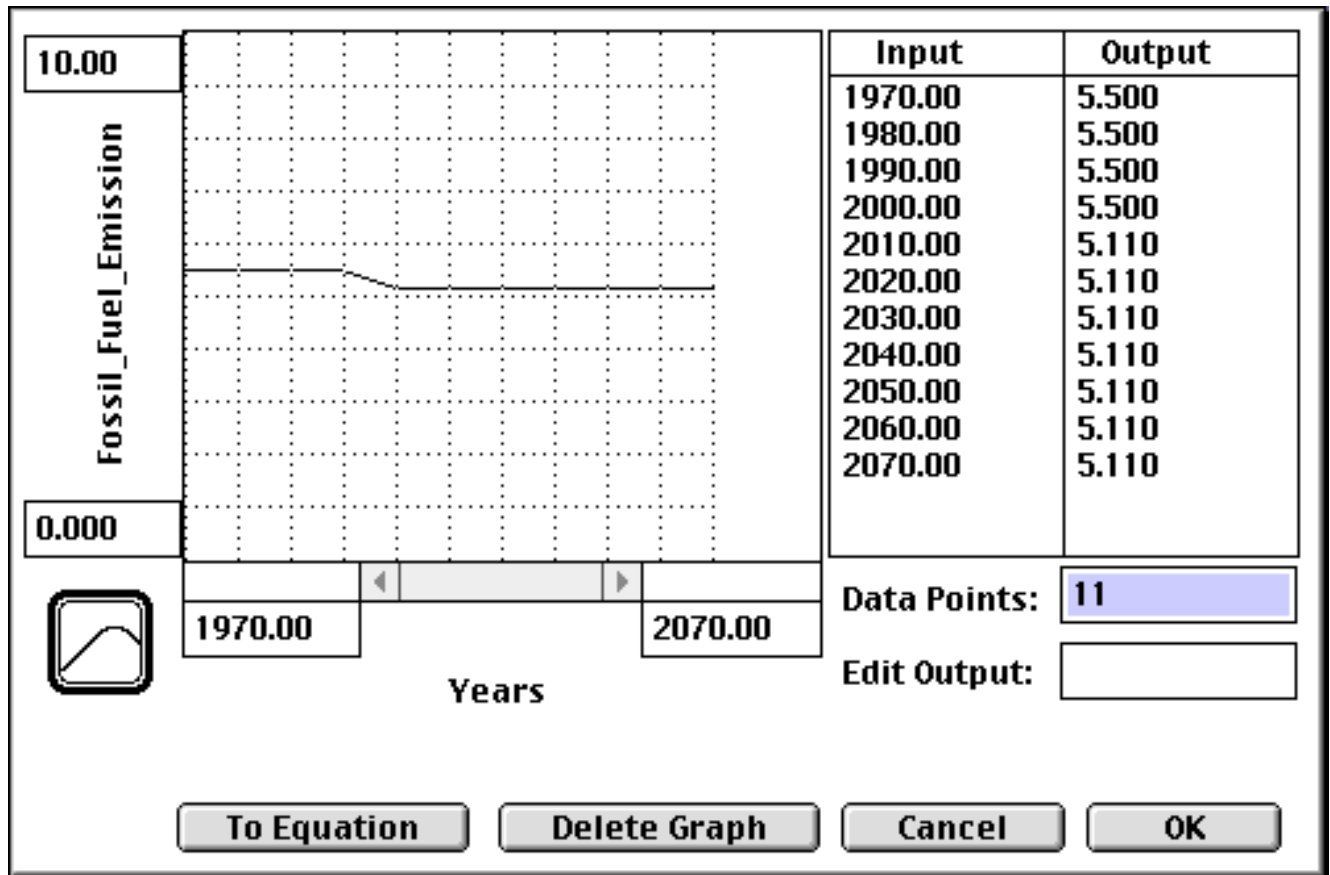
    Q19. Why is the scale 0 to 100 not appropriate for Fossil Fuel Emissions?

    Q20. What number would you choose for the maximum value on the y-axis?

35. Notice that the data table on the right side of the window has two columns, one labeled **Input** and the other labeled **Output**. Input means the independent variable and Output means the dependent variable. **STELLA** forces the scaling of the x-axis to be evenly spaced between the minimum and maximum values. Notice that the input column increments are not whole numbers because there are 13 data points.

- Change the number of data points to 11. Notice that the Input values increase in 10 year increments now.
- **Click** on each number in the **Output** column to enter the values for fossil fuel emissions.

36. Your window should be similar to this:

Input	Output
1970.00	5.500
1980.00	5.500
1990.00	5.500
2000.00	5.500
2010.00	5.110
2020.00	5.110
2030.00	5.110
2040.00	5.110
2050.00	5.110
2060.00	5.110
2070.00	5.110

10.00

0.000

Fossil_Fuel_Emission

1970.00   2070.00

Years

Data Points: 11

Edit Output:

To Equation   Delete Graph   Cancel   OK

37. When you are satisfied with your input graph. click **OK** and **run** your model.

> **Q21.** Using the numeric displays, record the final values of the stocks Atmosphere, Marine Biosphere and Terrestrial Biosphere.
>
> Atmosphere = _____   Marine Biosphere = _____   Terrestrial Biosphere = _____
>
> **Q22.** Does reducing the annual rate of fossil fuel emissions cause the amount of carbon in the atmosphere to return to its 1970 value? Describe what it does accomplish.
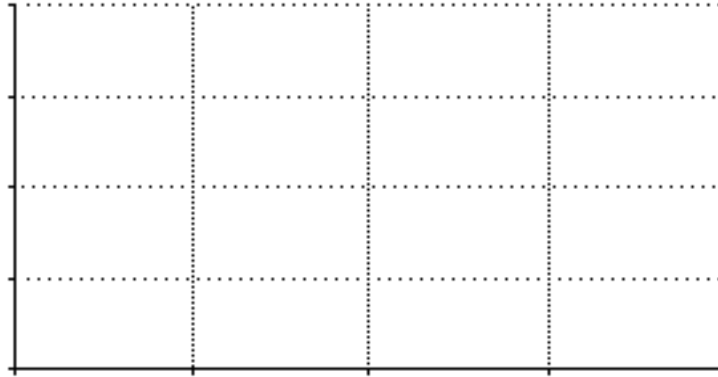>
>
>
>
>
>
> **Q23.** What do you think would be required to make the amount of carbon in the atmosphere decrease from the current high levels?

Part J. Eliminating fossil fuel emissions

38. Proponents of alternative energy sources believe the earth should ban fossil fuel emissions completely. Design a scenario which would gradually reduce emissions to zero, adjust your fossil fuel emission input graph and run it to see the results.

> **Q24.** Describe the changes you made to model the banning of fossil fuel emissions.

Q25. Show the results you achieved by sketching the output graph on the axes provided and recording the final values of Atmosphere, Marine Biosphere and Terrestrial Biosphere.

Atmosphere = _____   Marine Biosphere = _____   Terrestrial Biosphere = _____