Overview:
The California Climate Action Registry has developed a new Forest Sector Protocol to standardize a survey method to determine the amount of Carbon that is sequestered in a given area of forest. The ultimate goal is to attach a value to timber lands derived from their carbon sequestration amounts in addition to how they are currently valued for timber harvest potential or real estate development. There is a growing market in carbon trading and carbon offset credits and the hope is that carbon offset money can be used to finance the management of Sierra Forests as carbon sinks.

How much does a tree weigh?
This exercise will teach high school students how to "weigh a tree". The exercise focuses on carbon sequestration and carbon offsets. Specifically, it uses scientific and mathematic methods to actively show students the weight of a tree, the amount of carbon dioxide a tree sequesters, how many gallons of gas produces this amount of carbon, and how many trees would be needed to offset their own activities.

Background:
Carbon sequestration is the process of long-term carbon storage on land, underground, and in the oceans. Carbon dioxide (CO_2) is the principal greenhouse gas contributing to climate change. Carbon storage offsets CO_2 concentrations in the atmosphere by reducing or slowing buildup. One way to promote storage of CO_2 is by maintaining or enhancing natural processes. For example, we can identify ways to increase sequestration on land (www.science.doe.gov).

Through a process known as photosynthesis, living plants take in CO_2 from the atmosphere and release oxygen. Forest trees are the largest type of plants, and therefore act as carbon stores. They have the capacity to both emit and sequester CO_2. Trees, through photosynthesis, naturally absorb CO_2 from the atmosphere and store the gas as carbon in the roots, bole (trunk), branches, and leaves of the tree. Carbon is also stored in the soils that support the forest, as well as the understory plants and litter on the forest floor.

When trees are disturbed, through events like fire, disease or harvest, they emit their stored carbon as CO_2 into the atmosphere. Forests can act as a reservoir or source of carbon. Depending on how they are treated, they may have a positive or negative impact on the climate. Currently, forests are the second largest source of global anthropogenic CO_2 emissions, largely due to deforestation. Through proper management and protection, forests can also play a positive and significant role to help address global climate change (CCAR Protocol).

In this exercise, students will pick a tree on campus and:

- Use a key to identify the tree
- Take circumference and height measurements to determine diameter at breast height (DBH) and height of tree
- Apply species specific algorithm to estimate weight (biomass) of tree
- Determine amount of carbon stored, based on biomass

- Convert carbon weight to CO_2 weight

Students will then use these calculations to:

- Calculate gallons of gas burned to produce the same amount of CO_2
- Determine the number of trees needed to offset CO_2 emissions from driving different types of vehicles.

Step 1: Pick a tree, any tree…

Foresters need to estimate the amount of wood in a forest. For many years foresters carefully measured and weighed trees. They graphed the weight verses the diameter and height for each kind of tree. Next they found formulas that would reproduce the graphs. By using these formulas we can estimate a tree's green weight from its diameter and height.

- ✓ Choose a tree on campus. Try to find a tree that stands relatively straight. To make height estimates more accurate. Also, try to collect a bundle of needles or a cone from the tree, for identification purposes.

First, we need to find your tree's diameter. It is hard to measure through the center of a tree. We can measure the tree's circumference. A tree's circumference becomes smaller the higher up you climb. We need to agree on a place to measure the circumference. Foresters stand next to the tree and measure at chest height.

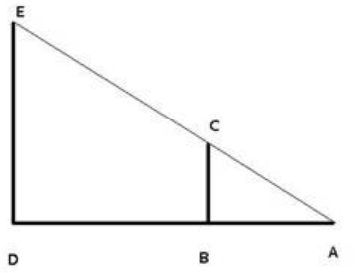
- ✓ Measure the circumference of the tree at breast height, using a measuring tape. Circumference = _____ cm
- ✓ Use circumference to calculate diameter at breast height (DBH). DBH= _____ cm

  ***remember $C=2\pi r$ and $D=2r$**

We can also find the height of the tree. Looking up the base of a tall pine may make this seem impossible, but it isn't. Using simple geometry, we can estimate the height of this tree.

- ✓ Using your measuring tape, measure the distance from your eye to fingers when your arm is fully extended in front of your face. Mark this distance on your measuring stick
- ✓ Hold your measuring stick at the "1", vertically, at fully extended arm length. Walk towards or away from the tree until the mark on the stick is visually lined up with the top of the tree and the bottom of the stick is lined up with the bottom of the tree. Keep your head as straight as possible. In sighting to the top and bottom of the stick rotate your eye rather then your head.
- ✓ Measure the distance from where you are standing to the base of the tree. Distance = _____ feet.

Convert feet to centimeters= _____cm. This is also equal to the height of the tree.



Remember: We have 2 similar triangles. ABC and ADE. They are similar because the measures of their angles are the same. The measure of AB isn't equal to the measure of AD. The ratio of the measure of BC/AB is equal to the ratio of the measure of DE/AD.

ary measurements, you can determine several things about your tree. Using the attached key, identify the species of tree you selected. For carbon calculations, you only need to know the species of tree, but we can determine genus as well.

- ✓ What is the species and genus of the tree you selected? What is the common name?

Step 3: Weigh your tree…

We have made two measurements: Diameter at Breast Height (dbh in cm) and height (H in cm). For each species of tree, there is an algorithm that can be used to determine the weight (biomass) of your tree.

- ✓ Select your species algorithm, and calculate the weight (biomass), using the dbh. For this exercise, height has already been factored into each algorithm.

Equations for Tree Species Biomass Estimates (kg) from CCAR Protocol

Incense Cedar	e^(-2.0336 + 2.2592 * ln DBH)
Douglas-fir	e^(-2.2304 + 2.4435 * ln DBH)
Pinus sp.	e^(-2.5356 + 2.4349 * ln DBH)
Abies sp.	e^(-2.5384 + 2.4814 * ln DBH)

Above ground biomass=_____kg

These algorithms calculate the biomass of the tree above ground. About 20% of the tree is found in the roots, below ground. The total biomass of the tree is the sum of the roots and above ground weights.

- ✓ Multiply the above ground biomass by .2 to find the weight of the roots.
  Root weight=_____kg
  Total biomass=_____kg

You have found the biomass of your tree. Living trees are made up of many chemicals, not just CO_2.

Step 4: How much CO_2 is in your tree?

Trees are 50% to 53% cellulose (dry weight). Cellulose is a polymer of sugar. Many sugar molecules are stuck together in a network to form cellulose. Another 1% is minerals, which result the ash you have after you burn wood. The minerals are elements like calcium and iron. The rest of the tree is lignin and some cytoplasm chemicals. Lignin is a group of protein chemicals that act like glue to help hold the cell wall together. When chemists analyze wood they find that 50% of a tree's dry weight is carbon.

- ✓ Find the weight of carbon in your tree by multiplying the tree's total biomass by .5
  Weight of carbon=_____kg
  In order to use this weight for the next step, we need to convert kg to g.
  _____kg= _____g of carbon

Using this estimate, we can calculate the CO_2 stored in the tree, based on the weight.

- ✓ Convert weight in C to CO_2
  Atomic weight of C=_____g/mol
  Atomic weight of O=_____g/mol
  CO_2 has ____ atom(s) of carbon and ____atom(s) of oxygen
  Therefore, atomic weight of CO_2=_____g/mol

We know from chemistry that the ratio of reactants and products for a chemical reaction is always the same

- ✓ Using the above calculations, we know the ratio of CO2/carbon is=____g CO_2 /____g C=_____g CO_2/g C
  If we multiply our tree's g of carbon * CO_2/carbon ration, the carbons cancel out and you are left with _____g of CO_2

Step 5: How much does a tree weigh?

Now we know the weight of CO_2 in our tree. Cars produce CO_2 by burning gasoline. For each gallon of gasoline burned, **20 pounds of CO_2 are produced**. When cars burn gasoline, they put CO_2 into the air. When trees grow, they take CO_2 out of the air.

- ✓ Calculate the number of gallons of gasoline (resulting in emissions) that are equivalent to the emissions sequestered by your tree.
  First, convert g of CO_2 to lbs=_____lbs CO_2
  ***Remember: 1 gram = 0.0022 pounds**
- ✓ How many gallons are equivalent to the number of pounds CO_2 your tree holds?

Using this information we can determine how many miles driven by a car to produce the same amount of CO_2 in your tree. The average household drives 20,895 miles per year. Calculate the number of trees needed to sequester the CO_2 produced by a family using each type of vehicle for one year.

Vehicle (2007)	MPG	Gallons	# of Trees

Ferrari	14	_____	_____
Ford 4WD Truck	16	_____	_____
Hummer	17	_____	_____
Subaru (AWD)	23	_____	_____
Prius (Hybrid)	55	_____	_____

Conclusions

We have calculated three different weights for your tree: the weight above the ground, the weight of the roots, and the total weight of the tree. Which of these should we use when we consider the tree's contribution to our air?

Every year your tree absorbs carbon to make its trunk larger and also to make new leaves. The carbon stays in the trunk. The carbon in the leaves returns to the air when the leaves rot the next year. Eventually, your tree will die or get cut down. What will happen to its carbon then?

How can we evaluate a tree or forest's long-term ability to counteract the CO_2 we are putting into the air?