For reference:

Photosynthesis: *CO2* + *H2O* + *energy* → *H2CO* + *O2*
Carbon fixation--organic molecules produced from carbon dioxide and water

Organic Transfers: Building and disassembling living tissue from organic molecules

Metabolism (aerobic respiration): *H2CO* + *O2* → *CO2* + *H2O* + *energy*
Combustion--organic molecules broken down into carbon dioxide and water to release energy



Photosynthesis occurs in chloroplasts, specialized structures within plant cells. Chloroplasts contain chlorophyll, a pigment that absorbs light, which provides the energy to rearrange chemical bonds, creating organic molecules from CO_2 and H_2O. Chlorophyll absorbs red and blue light and reflects green light. Thus, plant cells that are capable of photosynthesis thus appear green. In grass, almost all cells engage in photosynthesis, resulting in a uniform green blade. In a tree, leaves are specialized for photosynthesis, while branches and bark often lose their chlorophyll and green color.

Photosynthesis





Plants have a variety of strategies to optimize sun exposure through leaf arrangement. Within a single plant, it is a waste of resources to produce a leaf directly overtop another actively-photosynthesizing leaf, leading to spiraling patterns of leaf arrangement (left). The growth pattern of a plant also depends on the other plants producing shade in their environment. The same species will grow tall with a small spherical canopy when competing for sunlight in a forest environment as will produce low, expansive branches when growing alone, as the tree on the right is. Leaf production is costly, so the future payment in photosynthesizing capacity is important.





Flowering

Flowering plants, or angiosperms, represent only a subset of the living kingdom's photosynthesizing capacity, but they are a large portion of the plants that humans consider valuable, whether for agriculture or ornament. Though not always large and brightly colored, flowers are one of the most conspicuous destinies for newly fixed carbon. Through their shape, color, odor, positioning, and other features, flowers facilitate pollination, a key step for creating seeds. Investing organic matter in flower growth helps a plant ensure future generations.

Fruit and seeds

After pollination and fertilization within a flower, seeds and fruits form. Different types of plants allocate resources for their fruits and seeds differently. All plants balance the number of seeds they can produce against the amount of resources they allocate to each individual seed. Fruits usually surround the seed and can have a number of functions, from attracting seed dispersers or warning off seed predators to providing a physical barrier against abrasion of the seed or facilitating their buoyancy in the wind. Each of these forms requires a different set of organic molecules.





These small, black fruits are on display for animals to consume. The berry-like drupes of *Ilex glabra* (Inkberry) on the left are easily accessible to small mammals and birds. The hanging cluster of fruits on the right pose more of a challenge for mammals and will likely primarily be consumed by birds.









Small red fruits are often a sign of bird-dispersed seeds. Red is particularly striking against the backdrop of green leaves, making the fruits as appealing as possible to birds. The expenditure of sugars and other nutrients in the form of fruit is not directly useful to the plant, but the payoff in having seeds swallowed and transported by birds is apparently sufficient compensation. Flight requires a lot of energy, so sugars in the bird's diet are often combusted fairly soon after consumption.



The small fruits of *Myrica pensylvanica* are dull in color and positioned on branches interior to the leave. These inconspicuous fruits are often overlooked in the fall when animals store up on winter supplies. However, their waxy coating helps them survive well into the cold months, providing a steady supply of food to wintering birds, who in turn can be relied upon to eat the fruits and disperse their seeds year after year.



The dry fruits of *Cercis canadensis* split along their length to release small, light seeds that are carried off by wind. Legumes are made of different types of organic molecules than berries and other fleshy fruits, as are the seeds they carry. The seeds need to be small to carry on the wind, and there are many places they can land that will be inhospitable. The tree produces many small seeds, none of which individually require large investments of organic molecules. For plants with wind dispersed seeds, this is often the strategy that maximizes the potential for a new generation.

Legumes



Juniperus virginiana is a gymnosperm, meaning it does not produce flowers or fruit. More specifically, *J. virginiana* is a conifer. The misleadingly-named juniper berries are actually more closely related to pine cones than fruit. They serve a similar function as true berries--providing a stimulus for birds to swallow the tree's seeds, so that they can be dispersed at a distant location.

The woody cones of other conifer species function differently, mainly by providing airlift for seeds to be carried on the wind. As such, there is little incentive, in the form of sugar or digestible material, for birds or any animals to consume them.

Conifers



Leaf senescence

In the autumn, the organic molecules produced in the leaves of deciduous plants over the past several months undergo significant rearrangements. Were the plants to retain their spring leaves through the winter, they would likely be irreversibly damaged by the cold, dry air. So, plants reabsorb as many nutrients as it can and convert them into forms that can be stored in stems, buds, roots, and other structures. Especially important is the reabsorption of chlorophyll, which is why leaves often lose their green color in the fall. The more the plant strips from these leaves, the weaker they become until they fall from the plant. The fallen leaves are still made of organic molecules, but they have much less substance than their spring or summer selves. The majority of the leaves' photosynthetic products have been stored elsewhere in the plant.

Herbivory



This plant has clearly seen herbivorous activity. Most likely, birds have been plucking the fruits from their stems, but squirrels may have helped. Inside their digestive tracts, the fruit matter will be broken apart into its simplest organic building blocks--mainly sugars and maybe some amino acids and fatty acids. The animals cells can then take up these organic molecules and either metabolize them or incorporate them into new animal tissue.

The metabolic reaction is the opposite of photosynthesis. The rearrangement of chemical bonds results is a net release of energy, and the final products are photosynthesis starting blocks--carbon dioxide and water. Cells harness the energy released from this process, called cellular respiration, to do all kinds of work. One common form of respiration utilizes oxygen, making it a true mirror for photosynthesis. Aerobic respiration is found in all kinds of cells--bacteria, plant, fungi, and animals.



Nuts

This walnut represents a much different fruit form than the colorful, fleshy fruits pictured above. The fruit is a hard shell, encasing a fairly large seed that the tree has invested substantially in, in the form of organic molecules. Many will be eaten by small mammals foraging beneath the tree. A few may be forgotten after the mammal buries them for safe keeping. These seeds will germinate to potentially grow into adult *Juglans nigra*. For the nuts that get eaten, the seeds are destroyed. The organic molecules the tree has invested in those seeds are essentially a sacrifice so that hungry mammals will move the whole crop of nuts around.





Predation

Water birds use a variety of strategies to catch fish. Some float on the water's surface before diving deep into the water after their prey, like ducks (see movie: Duck). Others scan the water from the air above, usually searching for fish closer to the water's surface (see movie: Seagulls). Being in flight helps them remain undetected from their prey, although their shadows can still give them away.





Smaller birds tend to seek smaller prey. A large variety of bird species can be seen poking around in the grass for insects, alone or in groups.

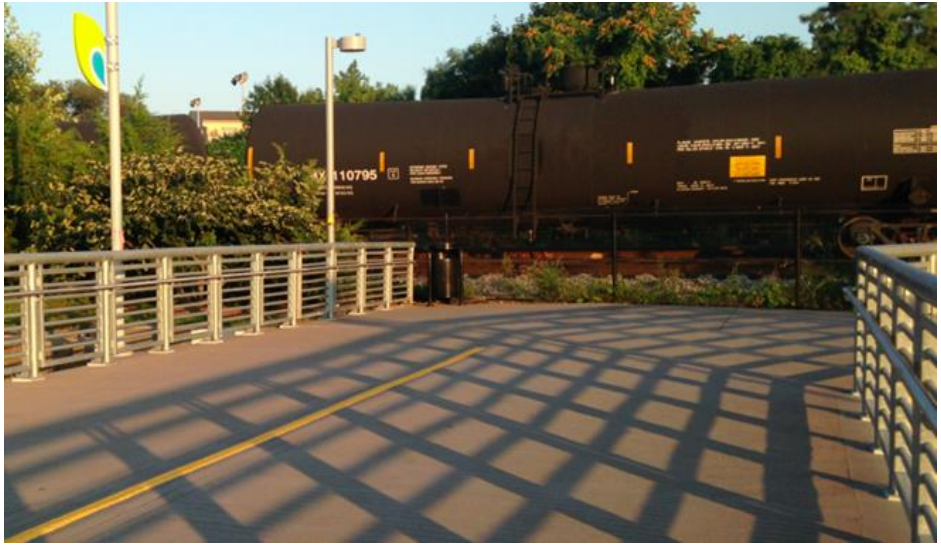


Decomposition



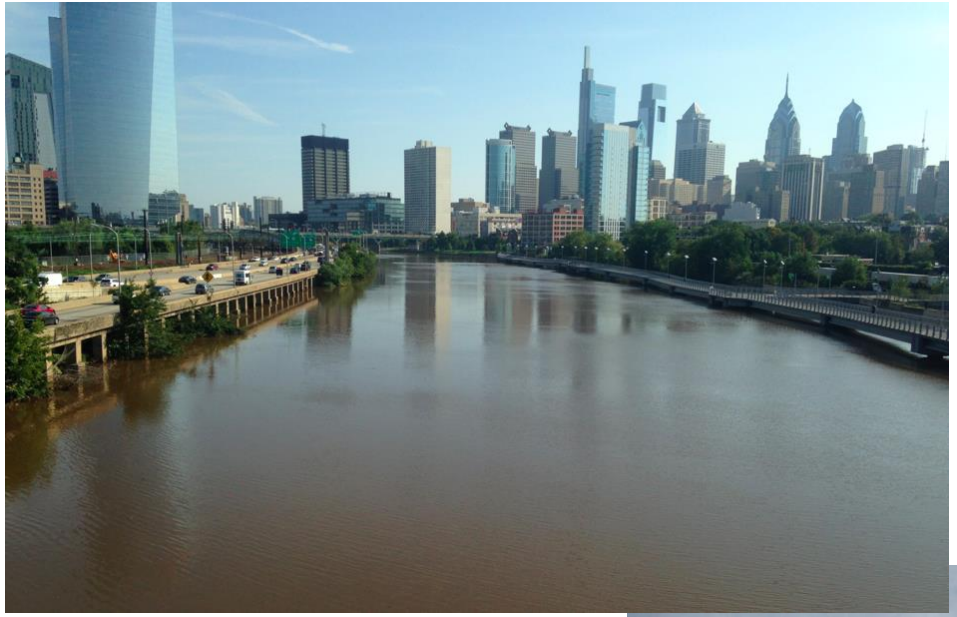
The organic matter that a plant or animal didn't burn for fuel before it dies will be combusted by other organisms after it dies. Some animals will eat already animals that are already dead, but the rest of the organic matter decomposes. Decomposition is essentially digestion and metabolism occurring outside of a body. Single celled bacteria and fungi secrete molecules to facilitate the deconstruction of organic matter into molecules small enoguh to take up in individual cells, where cellular respiration occurs.

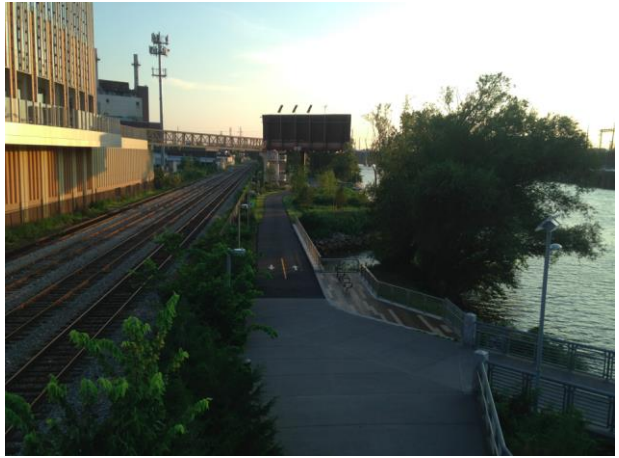




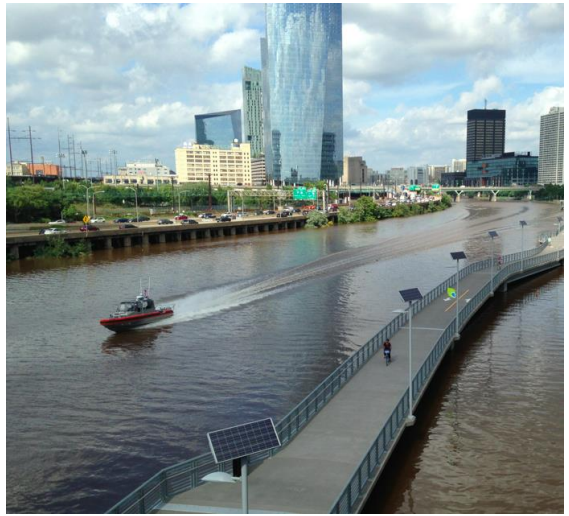
Fossil fuels

In certain conditions, dead organic material will not immediately decompose. If that organic matter is buried beneath the earth in high pressure and temperature conditions, after millions of years it forms concentrated chains of carbon and hydrogen. Humans have learned to excavate this concentrated organic matter from the earth in the form of coal, oil, and natural gas--fossil fuels. Here, natural gas is transported via train from the oil refinery on the Schuylkill River.









Cars and trains on either side of the river, speedboats on its surface, and planes flying overhead all operate on the combustion of fossil fuels.





Renewable energy

Human attempts to restore the balance of energy exchange include transforming the energy from sunlight and wind into electricity. Rather than millions of years, electricity from so-called renewable sources can be generated on a daily basis. In other words, solar panels and wind turbines operate on a timescale of days. The energy they generate can be stored temporarily in batteries, but it must be used shortly after it is stored.