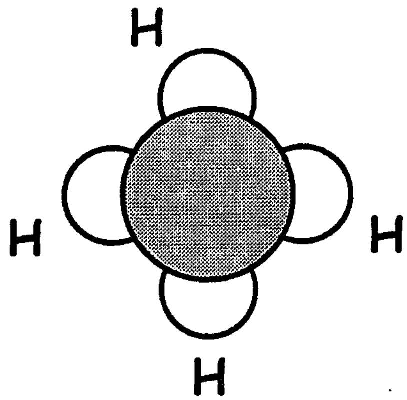
Teacher Background Information: Methane

Following carbon dioxide and water vapor, methane is the next most important greenhouse gas. A molecule of methane contains four carbon - hydrogen bonds and its chemical formula is CH_4. Methane absorbs at 7.7 nanometers (nm), at the edge of the infrared region of the electromagnetic spectrum. Per molecule, increasing the amount of methane in the atmosphere causes 23 times the warming effect as does adding more carbon dioxide, since methane molecules absorb a greater fraction of the thermal infrared (IR) photons that pass through than do CO_2 molecules. However, the 80 times greater increase in CO_2 molecules means that at present CH_4 is much less important in global warming. To date, methane is estimated to have produced about 1/3 as much of the global warming as carbon dioxide.



The atmospheric concentration of methane has almost doubled as compared with the pre-industrial value; almost all of this increase has occurred in the 20th century. Historically (before 1750), the methane concentration was constant at 0.75 parts per million (ppm), but in the 1980s, it rose by about 0.6% per year reaching 1.7 ppm. In the 1970s, the rate of increase was twice as large as this; it is not known with any certainty why the rate decreased and is now almost zero.

The rise in CH_4 levels is presumed to be the consequence of such human activities as increased food production, fossil fuel use and forest clearing. Methane is produced biologically in the anaerobic (oxygen limited) decomposition of plant material. Such processes occur on a huge scale where the decay of plants occur under water logged conditions, for example in natural wetlands such as swamps and bogs and in rice paddies. As a result, the original name for methane was "swamp gas " or "marsh gas". The expansion of wetlands that occurs by the flooding of land to produce hydroelectric power could add to this total. The production of methane from natural and artificial wetlands is currently considered to be the largest single source of this gas.

Ruminant animals - including cattle, sheep, and certain wild animals - produce methane in their stomachs as a by product of the digestion of cellulose in their foods and then emit methane into the air. The decrease in population of CH_4 emitting animals (e.g. buffalo) has been surpassed by the huge increases in the populations of cattle and sheep. Some of the reduction in the annual rate of increase of atmospheric methane may be due to the slow down in the acceleration in worldwide cattle production.

Anaerobic decomposition of the organic matter in garbage landfills is another important source of CH_4 in the air. In some communities, methane from landfills is collected and used to generate heat rather than being allowed to escape into the air. The burning of biomass, such as forests and grasslands, in tropical and semitropical regions, releases methane, along with larger amounts of carbon monoxide (CO) as a result of incomplete - poorly ventilated- combustion.

In summary, there are six different significant sources of atmospheric methane. In descending order of importance they are: wetlands, fossil fuels, landfills, ruminant animals, rice paddies and biomass burning.

The carbon in all living matter contains a small, constant fraction of a radioactive isotope - Carbon-14 (^{14}C), taken in through the carbon cycle when photosynthesis captures carbon dioxide from the atmosphere and when animals in turn feed off of the plant matter. The average fraction of ^{14}C found in atmospheric methane is less than the value found in living tissue, which indicates to scientists that some of the CH_4 escaping into the air must be "old carbon" that has been trapped in the ground for so long that its ^{14}C content has diminished to zero as a result of radioactive decay over time. Most methane containing old carbon is released into the air as a byproduct of the mining, processing and distribution of fossil fuels. Methane trapped in coal is released into the air when the material is mined, as is CH_4 in oil when it is pumped from the ground. The transmission of natural gas, which is almost entirely methane, involves losses into the air as a result of leakage from pipelines, and is the largest source of old carbon. Because of the losses of methane to the air that occur during transmission of natural gas, the *net* greenhouse-enhancing effect of using natural gas for combustion can be several times that of oil, even after the advantage of methane in producing less carbon dioxide per unit of heat produced is considered. Finally, there is a small contribution to the old carbon source from methane trapped in the permafrost in far northern latitudes; this methane was formed by the decay of plant matter that lived there many thousands of years ago when the polar climate was much warmer than it is today.

The dominant sink for atmospheric methane, which accounts for about 90% of its loss from the air, is through reaction with the hydroxyl free radical, OH^*:

$$CH_4 + OH^* \text{ ---------}\rightarrow CH_3^* + H_2O$$

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This reaction is the first step of a sequence that changes methane to CO and then to CO_2. The methane remains in the atmosphere approximately 15 years; the yearly loss from this reaction is about 480Tg (1Tg= 1 million metric tons). Scientists speculate that the concentration of hydroxyl radicals in the atmosphere may be decreasing because of the increasing levels of CO and CH_4 in the atmosphere, suggesting a feedback mechanism which in turn, may be causing the increase in the methane concentration.

There is a large amount of methane trapped in the bottom of the oceans on the continental shelves in the form of a *clathrate compounds*. Clathrates are 3-D lattice structures formed by water molecules under high pressure and low temperatures (such as would be found in cold waters and under ocean sediments) which "cage" the methane molecules within them. If the sea water warmed by an enhanced greenhouse effect penetrates to the bottom of the oceans, the clathrate compounds could decompose and release the trapped methane, as well as reservoirs of pure methane currently trapped below them, to the air above.

There are good data on the atmospheric concentrations of methane from Antarctica and Greenland ice cores for the period between 10,000 and 160,000 years. The minimum concentration during the last glacial periods (about 20,000 and 150,000 years ago) was around 0.35 ppmv, and rose rapidly, in conjunction with the observed temperature increases. To about 0.65 ppmv during the glacial-interglacial period (about 15,000 and 130,000 years ago. The concentration of methane decreased rapidly just before and during the last warming period between 10,000 and 11,000 years ago, during the period known as the Younger Dryas, a period of abrupt temperature decreases in Greenland and Northern Europe and increased rapidly after that.

Since then, the atmospheric concentration of methane has increased smoothly to present levels, highly correlated with the growing human population and are approximately double the pre-industrial value (1750-1800) and greater than at any time during the last 160,000 years. Analysis of infrared solar spectra has shown that the atmospheric methane concentration has increased by about 30% over the last 40 years. Atmospheric concentrations have been measured directly since 1978 when the globally averaged value was 1.51 ppmv; the current value is 1.72 ppmv. It is estimated that this value corresponds to an atmospheric reservoir of about 4900 Tg (1 Tg = 10^{12} g) and is increasing at a rate of 14-17 ppbv per year (40-48 Gt per year). The atmospheric concentration of CH_4 is higher in the Northern Hemisphere than in the Southern Hemisphere.

Several potential feedbacks exist between climate change and CH_4 emissions, in both tropical and high latitude wetland sources. In particular, an increase in high latitude temperatures could result in significant release of CH_4 from the melting of permafrost and the decomposition of CH_4 hydrates.