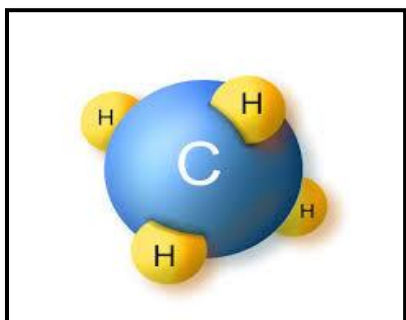


## CRITICAL THINKING ACTIVITY: THE METHANE CYCLE



### WHAT IS METHANE?

Methane is a chemical compound with the molecular formula  $\text{CH}_4$ . It is the main component in natural gas. Methane is considered the simplest of *alkanes*, compounds that consist only of hydrogen (H) and carbon (C) elements.

Methane is an odorless, colorless, tasteless gas that is lighter than air. When methane burns in the air it has a blue flame. In sufficient amounts of oxygen, methane burns to give off carbon dioxide ( $\text{CO}_2$ ) and water ( $\text{H}_2\text{O}$ ). When it undergoes combustion it produces a great amount of heat, which makes it very useful as a fuel source.

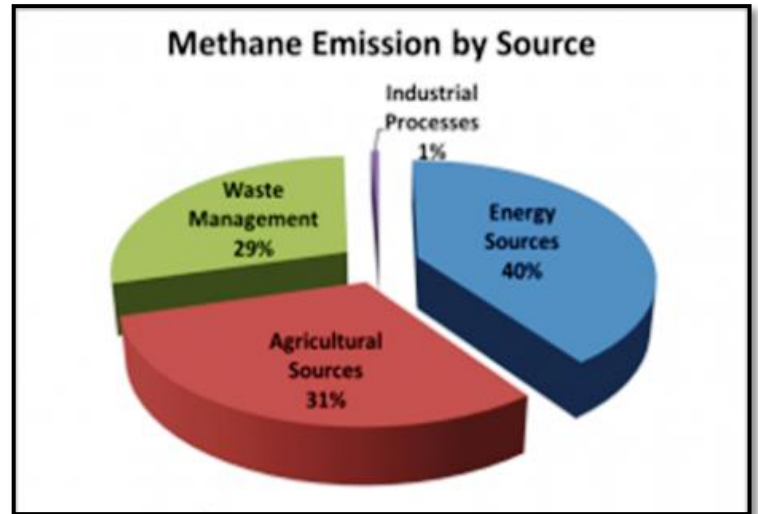


### METHANE AS A GREENHOUSE GAS

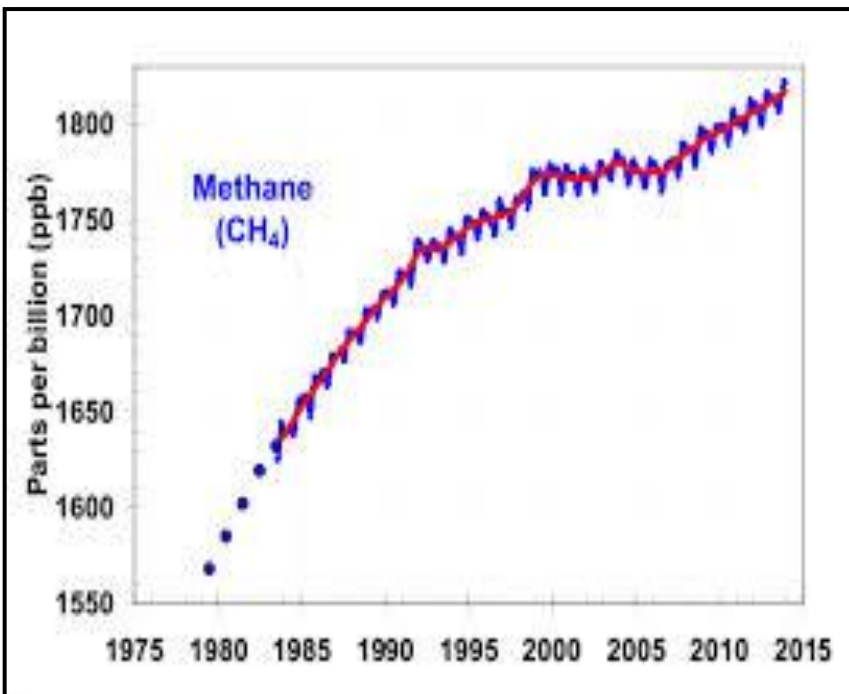
Methane is a very effective greenhouse gas. While its atmospheric concentration is much less than that of carbon dioxide, methane is 28 times more effective (averaged over 100 years) at trapping infrared radiation. The atmospheric residence time of methane is approximately 9 years. *Residence time* is the average time it takes for a molecule to be removed from the atmosphere. In this case, every molecule of methane that goes into the atmosphere remains there for 8 years until it is removed by oxidation into carbon dioxide ( $\text{CO}_2$ ) and water ( $\text{H}_2\text{O}$ ). It is difficult to quantify methane emissions since sources are spread out over large areas and emission values are small and variable in time and space.

## Student Sheet 2

It is estimated that up to 60% of the current methane flux from land to the atmosphere is the result of human activities. Some of these activities include emissions from fermentation processes associated with livestock, from cultivated rice paddies, from fossil fuel use and biomass burning, and from landfills.



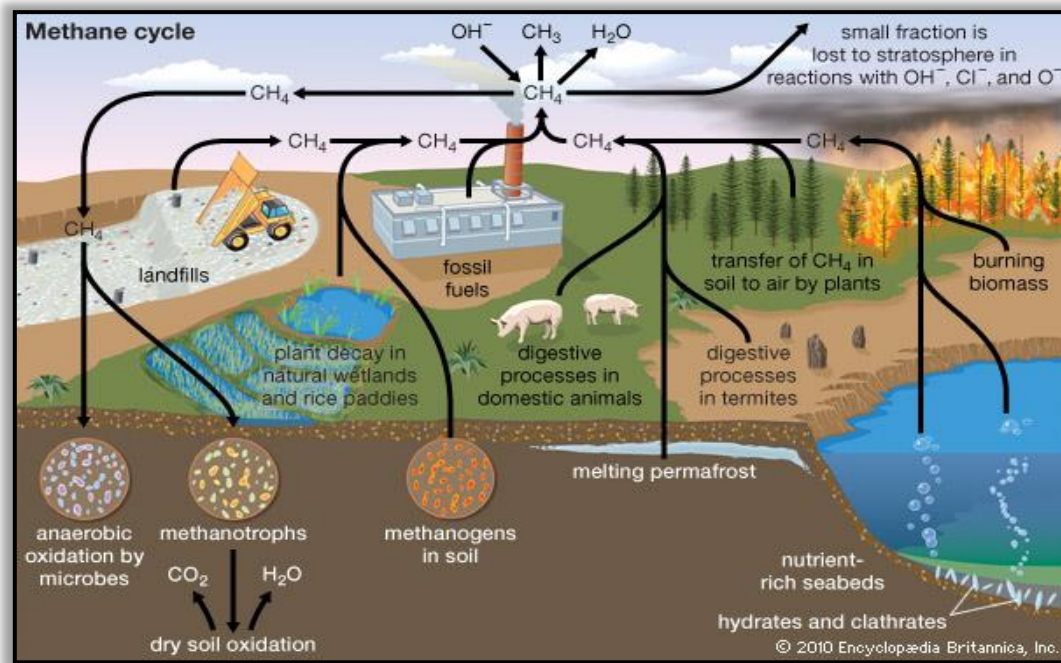
Methane concentrations have been increasing steadily for the past 200 years, and despite a decline from 1983-2006, it increased again in



2007. Over this time period, atmospheric methane concentrations have more than doubled. As with CO<sub>2</sub>, human activity is increasing the CH<sub>4</sub> concentration faster than natural sinks can offset it. Future trends are particularly difficult to

anticipate, partly due to an incomplete understanding of the climate feedbacks related to CH<sub>4</sub> emissions. It is also difficult to predict how, as human populations grow, possible changes in livestock raising, rice cultivation, and energy utilization will influence CH<sub>4</sub> emissions.

## THE METHANE CYCLE



This diagram of the methane cycle illustrates the flow of methane from **sources** into the atmosphere, as well as the **sinks** that consume methane

Most people have heard of the water cycle, in which water evaporates into the air, returns to Earth and then evaporates again. Many other substances, including methane, cycle this way too. There are many **sources** that release methane ( $\text{CH}_4$ ) into the atmosphere. There are also **sinks** or ways that methane is trapped or destroyed.

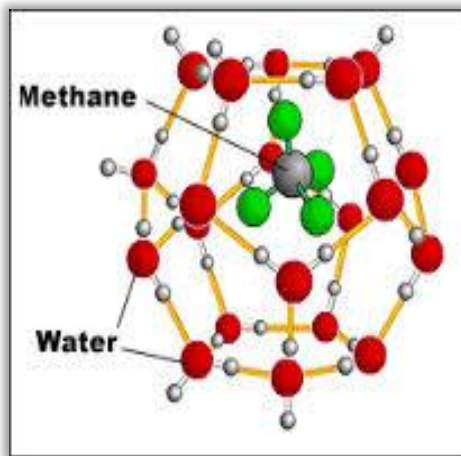
The methane cycle begins in the soil where methane gas is created by **microbes**. Soil methane is consumed by **methanotrophs**, microorganisms that feed on methane. **Methanogens** make more methane than methanotrophs consume. Methanotrophs live in drier soil layers above the deep, wet oxygen poor soils of swamps. Their "food" bubbles past them on its way to the surface, releasing methane into the atmosphere. This methane joins methane from other sources, such as landfills, livestock and exploitation of fossil fuels.

## Student Sheet 4



The main mechanism for removal of methane from the earth's atmosphere is oxidation within the troposphere by the *hydroxyl radical* (OH). A hydroxyl radical is a negatively charged oxygen atom bonded to a hydrogen atom (OH). Hydroxyl radicals are a form of "sink" because they "scrub" the atmosphere clean of pollutant molecules and break them down. For this reason OH is known as the 'cleanser of the atmosphere'. After reacting with OH, atmospheric methane is converted to  $\text{CO}_2$  by a long series of chemical reactions.) Some of the methane present in the troposphere passes into the stratosphere where the same process scrubs the atmosphere clean of methane there.

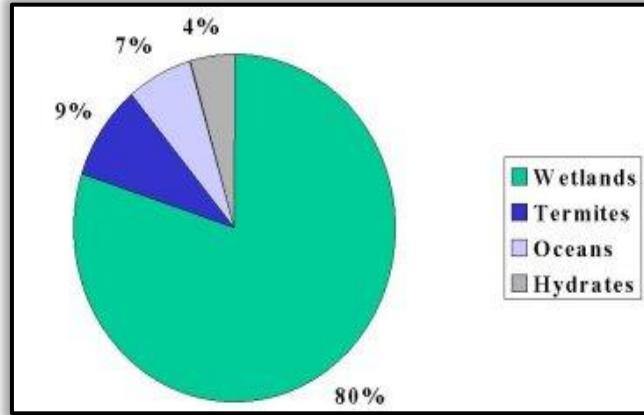
In an ideal world, methane sources would be balanced with methane sinks, as with  $\text{CO}_2$ , however, global atmospheric methane concentrations are rising as a result human activities. Scientists are worried because as the planet warms, even more methane will to be released from soils or other places adding to the global warming problem.



Methane crystals called *clathrates* form in cold, oxygen poor undersea sediments. Clathrates are also trapped in permafrost, the permanently frozen soil in the arctic and subarctic latitudes. Clathrate ice, also called *methane hydrate*, is solid and white, similar to water ice. However, this ice consists of water molecules that are frozen around molecules of methane. Clathrate deposits were once sinks where methane was isolated. However, as the planet warms, some of these deep, cold sediments are melting, sending methane bubbling to the surface. Because  $\text{CH}_4$  is a greenhouse gas, it traps heat in the atmosphere and warms the planet more.

## NATURAL SOURCES

Natural sources of methane include wetlands, gas hydrates, termites, oceans, freshwater bodies and other sources such as wildfires.



### + WETLANDS

Natural *wetlands* are responsible for approximately 80% of global methane emissions from natural sources.

Wetlands, such as bogs, marshes, fens and permafrost provide a habitat favorable to microbes that produce methane during the decomposition of organic material.

These microbes require environments with no oxygen and plentiful organic matter, both of which are present in wetland conditions. Wetlands contribute approximately 140-280 Tg (million metric tons) to the global methane budget each year.



### + TERMITES



Global methane emissions from *termites* and their mounds are estimated to be about 11% of the global methane emissions from natural sources or about 2-20 Tg per year. Microbes in the guts of termites produce methane as part of their normal digestive process,

and the amount generated varies among different species. The emissions contributed by termites depend largely on the population of these insects, which varies significantly in different regions.

## Student Sheet 6

### + OCEANS

*Oceans* are estimated to be responsible for about 8% of the global methane emissions from natural sources or between 20-30 Tg yearly. The source of methane from oceans is not entirely clear, but two identified sources include the anaerobic (oxygen-free) digestion in marine zooplankton and fish, and also from methane produced in sediments and drainage areas along coastal regions.



### + METHANE HYDRATES

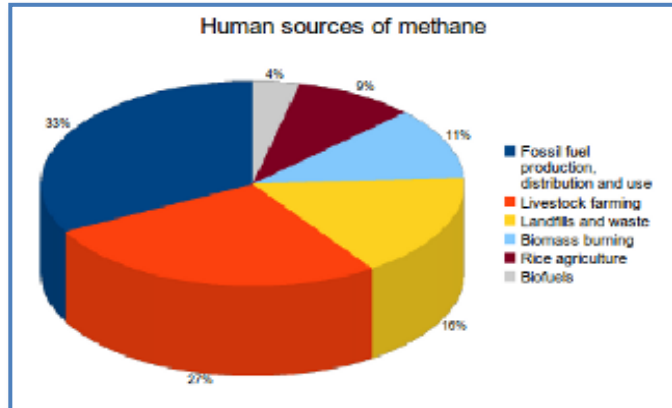


Global emissions from *methane hydrates* accounts for approximately 5% of the global methane emissions from natural sources. Methane hydrates are molecules of methane that are frozen into ice crystals. We're not sure exactly how much methane is trapped in methyl hydrates, or how much is in danger of escaping. Overall, the amount of methane stored in these hydrates globally is estimated to be very large, making the

potential for the release of large quantities of methane a real possibility if serious breakdowns in the stability of the deposits were to occur.

## HUMAN SOURCES

*Human activities that produce methane include fossil fuel production, the livestock industry, rice cultivation, biomass burning, and waste management. These activities release significant quantities of methane to the atmosphere.*



### LANDFILLS

Methane is generated in landfills and open dumps as waste decomposes under anaerobic conditions (oxygen-free). The amount of methane created depends on the quantity and moisture content of the waste and the design and management practices at the site. Landfills in regions with dry conditions are not as productive as those in area with high moisture content. In 2012, landfills contributed 102.8 Tg of methane to the atmosphere.



### FOSSIL FUELS

Fossil fuels are formed by natural processes such as anaerobic decomposition of buried dead organisms. Fossil fuels contain high percentages of carbon and include coal, petroleum, and natural gas.

## Student Sheet 8

Methane is the primary component of natural gas. Methane is released during the production, processing, storage, transmission, and distribution of natural gas. Because natural gas is often found with oil, the collection and combustion of oil also contributes to the total methane emissions. In addition, methane trapped in coal deposits is released during normal mining operations in both underground and surface mines. According to the **2013 IPCC Report**, the combined retrieval and use of fossil fuels contributed approximately 85-100 Tg of methane to the atmosphere.



### + LIVESTOCK

Domesticated livestock such as cattle, buffalo, sheep, goats, and camels produce large amounts of methane as part of their normal digestive processes. In the large, first stomach of these animals, *microbial fermentation* converts feed into products that can be digested and

utilized by the animal. This process produces methane as a by-product, which is exhaled by the animal (cow breath). Methane is also produced in smaller quantities by the digestive processes of other animals, including humans, but emissions from these sources are insignificant. Livestock contributions are place between 85-95 Tg (1 Tg = 1 trillion metric tons) each year.

### + WASTEWATER TREATMENT

**Wastewater** from sewage is treated to remove soluble organic matter, suspended solids, pathogenic organisms, and chemical contaminants. These treatment processes can produce methane emissions if organic ingredients in the wastewater are treated without





oxygen and if the methane produced is released to the atmosphere. In addition, the sludge produced from some treatment processes may be further biodegraded under anaerobic conditions, resulting in methane emissions. Wastewater treatments adds approximately 12.8 Tg of methane each year.



## RICE CULTIVATION

Methane is produced during flooded *rice cultivation* by the decomposition of organic matter in the soil. Flooded soils are ideal environments for methane production because of their high levels of organic substrates, oxygen-poor conditions, and moisture. The level of emissions depends upon soil conditions and production practices as well as climate. There are cultivation practices that could possibly be helpful in reducing methane emissions from rice cultivation. Without them, rice production adds between 7.4 Tg per year.

A sudden stop in the emissions of methane is an unlikely scenario, but there is potential for reducing emissions. Recent data shows that the short lifetime gases, which include methane, peak earlier and drop away rapidly. This suggests that policies targeting them should lead to noticeable reductions in atmospheric concentrations. Reducing emissions of methane could be a valuable means of slowing global temperature rise.