Where Methane Meets Microbiology

THE MICROBIAL ROLE IN CLIMATE CHANGE

Methane is the largest component of natural gas.

It is the second most abundant greenhouse gas and the biggest contributor to global warming after carbon dioxide.

Looking at a 100-year horizon, methane has **28 times** more global warming potential (GWP_{100}) than carbon dioxide.

In the past 150 years, methane has added **0.5°C to global warming**.

70% of all methane comes from **microbes**.

This means a large portion of global warming is believed to be microbially controlled.

Humans are responsible for much of these emissions by creating environments where these microbes thrive.

Methane Makers

The microbial organisms that produce methane are called **methanogens**.

They produce methane as part of the final step in the breakdown of organic matter, and they exist in many different environments across the world.

All methanogens are single-celled organisms belonging to the domain of **Archaea**, a group of lifeforms that differ in their cellular composition and structure from both Bacteria and Eukaryotes (which includes animals, plants, and fungi).

All methanogens are **anaerobic**—unlike us, they **cannot survive with oxygen**, and most thrive in environments that are completely devoid of it!

The current record for growth at **extremely high temperatures** belongs to a methanogen. *Methanopyrus kandleri* grows in the smoker fluid of hydrothermal vents at 122°C/252°F!

Methane Munchers

Methanotrophs are microbes that consume methane for energy.

This ability has given them special consideration in the effort to reduce both natural and anthropogenic methane emissions.

In contrast to methanogens, methanotrophs are distributed within both the domains of **Bacteria** and **Archaea.**

Methanotrophs can be either **aerobic** or **anaerobic**. Some **require oxygen** to live and grow, while others **cannot survive in the presence of oxygen**.

Although an anaerobe, *Methylomirabilis oxyfera* **produces oxygen** in its cell to convert methane. This bacterium catalyzes one of only a handful of reactions known to produce molecular oxygen.

FUN FACT
Methanogenesis is estimated to be more than 3 billion years old, making it an ancient metabolism.

Methanogenesis

Methane is formed as a byproduct when methanogens metabolize their food sources to gain energy. This microbial process of creating methane is called **methanogenesis**.

Methanogenesis can be accomplished by different reactions. Two very common ones are:

CO_2-reducing methanogenesis

carbon dioxide + **4** hydrogen molecules → methane + **2** water molecules

Acetoclastic methanogenesis

acetate → carbon dioxide + methane

**These are two examples of many other kinds of methanogenic reactions using different starting chemicals.*

Methanotrophy

Methanotrophs consume methane to harness energy in a process called **methanotrophy**.

Unlike methanogenesis, methanotrophy exists in both oxygen-free and oxygen-containing environments. Oxygen is used to convert methane, but in environments without oxygen other compounds substitute for it.

FUN FACT
In an example of microbial symbiosis, methanotrophic aggregates of archaea and bacteria convert methane to carbon dioxide.

Aerobic methanotrophy

methane + **2** oxygen molecules → carbon dioxide + **2** water molecules

Anaerobic methanotrophy (with sulfate)

methane + sulfate → bicarbonate + hydrogen sulfide + water molecule

**These are the two most important types of methanotrophy, but many other reactions exist.*

Where in the World is Methane Made?

- Ruminant Guts
- Landfills
- Rice Paddies
- Peatland/Bogs

Where in the World is Methane Munched?

- Sediments above Deep Sea Methane Hydrates
- Bodies of Water
- Soils
- Atmosphere

The Global Methane Budget

The global methane budget represents the balance of methane emissions and removals in the Earth's atmosphere. The diagrams show the most important environments in which methane is emitted from (sources) and degraded (sinks). The majority of methane made by microbes or released from gas hydrates is immediately converted by microbes and never reaches the atmosphere; it is recycled. These diagrams show net emissions of methane and removals from the atmosphere.

Total Emissions 576-737 million metric tons/year

Total Sinks 556-625 million metric tons/year

Methanogens produce approximately 1 billion metric tons of methane annually. Deep sea gas hydrates release another 1 billion tons.

Approximately three quarters of the methane is recycled by methanotrophs and never reaches the atmosphere. Most methane is converted to carbon dioxide, which is then taken up by other lifeforms.

New Sources of Methane and their Makers

Finding methane in oxygen-rich oceans and fresh water, where methanogens cannot survive, is a headscratcher. Recent research indicated that enzymes called **C-P lyases** and **Aspartate amino transferases** are responsible for this methane.

For more than 40 years methanogenesis was thought to be restricted to a single lineage of archaea. New research suggests that many more lineages of archaea can grow by methanogenesis, raising important questions about which of these microbes make methane in the environment.

In some cell types, abiotic reactions produce tiny amounts of methane due to oxygen stress in cells and tissues.

Methanotrophs as Crisis Curbers

Methane hydrates are cages of ice in which methane is trapped. The energy stored in these hydrates is larger than that stored in all coal, gas, and oil combined.

Hydrates can leak into the water column and the atmosphere through cold seeps at the bottom of the ocean, where anaerobic methanotrophs convert approximately 90% of the leaking methane into carbonate deposits that build microbial reefs.

Methane hydrates are scattered all over the oceans' floors. Methane leaked from methane hydrates likely resulted in mass extinction events in the past. Today, methanotrophs remove ~90% of that leaked methane so that it never reaches the atmosphere.

IMPORTANT SOURCES

[1] Saunois et al. *The Global Methane Budget 2000-2017.* Earth Syst Sci Data (2020). [2] Intergovernmental Panel on Climate Change. *Climate Change 2021. The Physical Science Basis. Summary for Policymakers.* (2021) [3] Garcia et al. *Diversity and Evolution of Methane-Related Pathways in Archaea.* Annu Rev Microbiol (2022). [4] Thauer et al. *Methanogenic archaea: ecologically relevant differences in energy conservation.* Nat Rev Microbiol (2008) [5] Knittel and Boetius. *Anaerobic oxidation of methane: progress with an unknown process.* Annu Rev Microbiol 63 (2009). [6] Evans et al. *An evolving view of methane metabolism in the Archaea.* Nat Rev Microbiol (2019)

Content & Research by Roland Hatzenpichler | www.environmental-microbiology.com

Art & Design by Mark Belan | www.artscistudios.com; some assets from Iconscouts.com (CC)

Citation | DOI:10.5281/zenodo.13312690

artsci STUDIOS
artscistudios.com