

# Methane: a natural gas

The methane produced by microbes is a big contributor to global warming, but as **Setareh** and **James Chong** describe, it also has great potential as a source of green energy.

Some believe that methanogens may be among the most ancient forms of life. What is the evidence for this? These single-celled prokaryotic organisms belong to the domain *Archaea*, itself a lineage of cells that appear to be deeply rooted between the eubacteria ('true' bacteria) and the eukaryotes. Archaea were originally called archaeobacteria until the 'Archaea-ologists' felt a name that more obviously demonstrated the differences between these organisms and eubacteria was required. While the archaea are best known for their love of extremes – the most thermophilic, acidophilic, halophilic (salt-loving) and barophilic (pressure-loving) organisms all belong to this domain – most methanogens show distinctly mesophilic tendencies. However, methanogens require an environment containing less than 10 p.p.m. O<sub>2</sub> (i.e. <0.001 %) to grow! For most oxygen-requiring life, this could be considered to be rather extreme. This very low oxygen concentration coincides with the probable composition of the atmosphere of anoxic Earth some 2.5 billion

years ago, before the 'great oxygenation event' that was triggered by the evolution of microbial photosynthesis. Methanogens have evolved a unique metabolism that allows them to survive on the energy generated by the reduction of CO<sub>2</sub> and other small carbon compounds by hydrogen. This is not a particularly energetically favourable process and results in the biological generation of methane as a waste product (hence the name). The 'methanogens-as-one-of-the-earliest-forms-of-life' theory suggests that methane excreted by methanogens could have helped to warm primordial Earth.

## Biological methane

Methanogens are the main source of biological methane on the planet, producing in the order of a billion tonnes per annum globally. Methane is a serious greenhouse gas with 23 times the global warming potential (GWP) of CO<sub>2</sub> over 100 years. That is, a single molecule of methane released into the atmosphere has the same thermal retention capacity as 23 molecules of CO<sub>2</sub> over 100 years. The warming effect

of methane is even worse over a shorter time scale – it has a GWP of 68 over 20 years – but it is a relatively unstable molecule once in the upper atmosphere. Contemplating the numbers is a rather frightening prospect: if all the methane produced by methanogens each year reached the atmosphere, it would be the equivalent of releasing 23 billion tonnes of CO<sub>2</sub>. Current global CO<sub>2</sub> emissions are about 8 billion tonnes per year; thus, methanogens have the potential to provide three times the heating effect of anthropogenic carbon emissions! Fortunately, a large proportion of methanogen-produced methane is captured by other, methanotrophic, bacteria that can in turn use methane as an energy source.

◀ Computer models of methane molecules. Prof. K. Seddon & J. Van Den Berg / Queen's University, Belfast / Science Photo Library

▲ Natural gas burning. Photos.com / Jupiter Images

## Biofuel potential

Of course, not only methanotrophs can use methane for energy. The major flammable component of natural gas is methane. Natural gas is currently the fossil fuel of choice due to its relatively clean burning properties and it provides more than 40 % of current energy needs in the UK. Methane is an odourless gas (if you work with methanogens you always need to get this into the conversation early!) that is relatively easy to handle, and burns with oxygen to produce only water and CO<sub>2</sub>. Two of the main problems with

natural gas/methane as a fuel source are the production of CO<sub>2</sub> and the fact that as a fossil fuel, natural gas is a finite source of energy. Methane from methanogens does not have the same problems. Methanogenic methane is renewable, and formed from recently fixed atmospheric CO<sub>2</sub>, so burning methane from a methanogenic source is effectively carbon neutral.

## Anaerobic digestion

In the microbial world, methanogens are terminal electron acceptors, taking the breakdown products from

consortia of (mainly) constitutively anaerobic bacteria at the end of the organic degradation process. Anaerobic digestion (AD) has long been used as a low-tech, environmentally friendly, way to process organic waste into 'biogas'. Biogas is a mixture of CO<sub>2</sub> and methane that can be burned in much the same way as natural gas to provide both heat and power. Anaerobic digesters tend to be more popular in countries with warmer environments where the natural processes involved in organic matter breakdown are perceived as faster. However, a number of facilities exist in the UK (mainly for processing wastewater) that also make use of methanogens. AD has also seen a recent rise in popularity in continental Europe, where incentives for green energy production have made electricity generated from biogas a cost-effective method of disposing of plant and other agricultural waste. In the USA in 2000, the amount of electricity produced by AD from agricultural sources was

insignificantly low. However, by 2007 agricultural AD from a relatively small number of facilities in the USA was responsible for the production of more than 215,000,000 kWh of electricity, emphasizing how rapidly and effectively this technology can be deployed.

In the UK, AD is still a very under-used technology despite Defra recently making it the preferred method for disposing of food waste. AD is perceived as an unreliable and difficult technology to use in the UK – something that works better at higher ambient temperatures. There is no scientific basis for these notions. The Arctic tundra has been estimated to contain as much as 32,000 Gt (1 Gt = 10<sup>9</sup> tonnes) of methane generated by the slow action of methanogenic degradation of organic matter trapped under the permafrost. So methanogens and their associated consortia of anaerobes can certainly tolerate the British climate. Methanogens, perhaps due to their



great ancientness, or perhaps due to the pervasiveness of oxygen forcing them to hide, have been found in all of the anaerobic ecological niches explored to date. There are thermophilic methanogens (the first archaeal genome to be sequenced was of the hyperthermophilic *Methanocaldococcus jannaschii*, which grows at 85 °C), halophilic methanogens and psychrophilic methanogens (isolated from Antarctica).

#### Methanogen habitats

Alessandro Volta (the scientist who first described the Volt) was the first person to describe methane from

microbes, which he observed by igniting 'combustible air' collected from marshes in northern Italy in 1776. As well as being hugely abundant in rice paddies, swamps and landfill sites, methanogens are endemic in ruminants (responsible for as much as 15% of global methane emissions), termites and other insects (5% of global methane emissions are due to methanogens in termite guts). The limited studies that exist concerning the presence of methanogens in human guts vary wildly, but it seems likely that more than 30% of the population contain methanogens in their guts, and



that their presence is good for your gut flora.

#### Growing pains

Despite their abundance, growing methanogens in the laboratory poses a significant challenge; gases need to be scrubbed of all traces of oxygen, and hydrogen must be handled in a non-explosive manner. Large quantities of strong reducing agents (mainly sulfur-containing compounds) do lend a certain pall to the atmosphere that perhaps justifies the initial reaction many people have to the thought of working with methanogens – this kind

of microbiology can be smelly! However, growing methanogens alone is nothing compared with trying to grow a stably-interacting mixed population of anaerobes. But in order to understand the dynamics that occur in these consortia, these issues must be resolved. Consortial dynamics need to be measured, understood and modelled so that the robust but rather inefficient process of anaerobic digestion can be improved and added to the range of green energy/biofuel options currently being examined as alternatives to mankind's dependence on fossil fuels. This is a microbiological challenge that should no longer be neglected.

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#### Further reading

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▲ *Top left.* Microscale methane generation. Termites are equipped with portable anaerobic digesters that contain a huge diversity of specialized microbes for the breakdown of lignocellulose. *Photos.com / Jupiter Images*

▲ *Top right.* A scanning electron micrograph of *Methanothermobacter thermautotrophicus*. This organism was originally isolated from sewage sludge and grows optimally at 60 °C. Bar, 5 µm. *Meg Stark & Paul McDermott*

◀ *Far left.* Methanogens growing in captivity. A 2 litre culture of *Methanococcus maripaludis* growing on an 80:20 mix of H<sub>2</sub> and CO<sub>2</sub>. Methane is produced as a waste product by all methanogens. *James Chong*

◀ *Sushi and burgers make methane.* Paddy fields are one of the major anthropogenic methanogen niches that are expanding. In 2005, global rice cultivation was responsible for the emission of ~32 million tonnes of methane (the equivalent of 672 million tonnes of CO<sub>2</sub>) – more than the UK's total greenhouse gas emissions for the same year. Global enteric fermentation produced nearly three times this amount of methane (92 million tonnes) in 2005. *James Chong*

