Glossary

Abandoned coal mines	Mines which are no longer being mined for coal
Abatement	A reduction in the amount or intensity of emissions
Active coal mines	Mines which are still operative and producing coal, either deep mines or open cast
Additionality	A requirement that emissions reductions associated with a greenhouse gas mitigation project must exceed those that would have occurred in the absence of the project
Aerobic	In the presence of, or requiring, oxygen
Allowances	The right to emit a quantity of a pollutant under an emissions trading scheme
Anaerobic	In the absence of oxygen
Anthropogenic	Made by humans or resulting from human activity
Baseline-and-credit system	A market-based approach which allocates a pre-determined emissions profile to each participant and allows trade in the unused portion of that profile
Bedrock	The solid rock that underlies soil and other loose material
Biodegradable	Material that can be broken down by micro-organisms into simpler compounds
Biogas	A combustible gas created by the anaerobic decomposition of organic material, composed primarily of methane, carbon dioxide and hydrogen sulphide. This can be produced at landfill sites, wastewater treatment facilities and animal waste treatment facilities
Biogasification	The breakdown of complex biological materials by anaerobic bacteria to more useful forms of fuel: carbon dioxide and methane
Biogenic	Produced by the action of living organisms or biological processes
Biomass	Plant-based materials that can be burned to produce energy or converted into a gas and used for fuel
BSE	Bovine Spongiform Encephalopathy is a chronic progressive degenerative disease affecting the central nervous system of adult cattle, also known as Mad Cow Disease
Calorific value	The heat produced by the complete combustion of a given quantity of fuel under specific conditions, measured in calories. The calorific value of household waste is about one-third that of coal
Cap-and-trade system	A market-based approach where a cap, or maximum limit, is set on emissions and sources covered by the system receive authorisations to emit in the form of emissions allowances, with the total amount of allowances limited by the cap
Capping layer	An impermeable layer of clay or artificial membrane near the surface of a landfill site forming a barrier between the contaminated material and the atmosphere. The cap is designed to keep water out (to prevent leachate formation) and also helps to capture landfill gas

Carbon credits	An amount of carbon that has been mitigated by a project that can then be used as a tradable commodity to offset greenhouse gas emissions
Carbon cycle	The exchange of carbon in various forms (carbon dioxide, carbonates, organic compounds *etc.*) between the atmosphere, ocean, terrestrial biosphere and geological deposits
CDM	The Clean Development Mechanism is a market mechanism defined in the Kyoto Protocol (Article 12) as a project between a developed country and a developing country that provides the latter with the financing and technology for sustainable development, and assists in achieving compliance with its emission reduction commitments
Clear Skies Programme	UK capital grant scheme for promoting renewable energy technologies including solar thermal, biomass boilers and heat pumps
Climate change	A long-term change in temperature, precipitation, wind and all other aspects of the earth's climate due to natural or human activity. Climate change is defined by the United Nations Framework Convention on Climate Change as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods"
Co-firing	The use of two or more different fuels (*e.g.* wood and coal) simultaneously in the combustion chamber of a power plant
Composting	Biological decomposition of organic materials in the presence of oxygen by bacteria, fungi and other organisms into a soil-like product called humus
Condensate	A light liquid hydrocarbon produced when hydrocarbon vapours are cooled
Digesta	Intestinal contents
Digestate	The solid residue produced in an anaerobic digester, similar to compost. The digestate usually requires stabilisation by composting before a saleable product can be produced
Dioxins	Highly toxic compounds that are a by-product of incineration of plastics. Also generated by bush fires, volcanoes and vehicle emissions
Direct emissions	Greenhouse gas emissions by an entity from sources owned or controlled by that entity
Energy recovery	The process of extracting useful energy from waste, typically electricity or heat (or both)
Enhanced greenhouse effect	The increase in the natural greenhouse effect through increased concentrations of greenhouse gases as a result of human activities
Enteric fermentation	A digestive process of some mammals by which carbohydrates are broken down by micro-organisms into simple molecules to aid absorption into the bloodstream

Eutrophication	The process by which water becomes enriched with plant nutrients, most commonly phosphates and nitrates. This promotes algae growth which, when it dies, can lead to the depletion of dissolved oxygen, killing fish and other aquatic organisms. While eutrophication is a natural, slow-aging process for a body of water, human activities can greatly accelerate the process
Feed-in tariffs	A form of support for electricity generated from renewable sources. Typically a premium price is paid to generators of green electricity
Financial derivatives	A risk-shifting agreement, the value of which is derived from the value of an underlying asset. The underlying asset could be a physical commodity, an interest rate, a company's stock, a stock index, a currency, or virtually any other tradable instrument upon which two parties can agree
Flange	A device to connect a pipe to another pipe, a valve or other piece of equipment, and maintain a seal
Foot and Mouth disease	An acute contagious viral disease of cloven-footed animals (*e.g.* cattle, sheep, goats, pigs) marked by ulcers in the mouth and around the hoofs
Fossil fuel	Naturally occurring carbon or hydrocarbon fuel (*e.g.* coal, natural gas and oil) formed by the decomposition of ancient animal and plant remains formed over millions of years
Gate fee	The fee, usually quoted in £ per tonne, for processing waste at a treatment and/or disposal facility
Global warming	The rise in temperature of the earth's surface due to the enhanced greenhouse effect
Global Warming Potential	A measure of the relative strengths of different greenhouse gases. Defined as the cumulative radiative forcing of the gas compared to carbon dioxide over a specified time horizon (usually 100 years)
Grandfathering	A method of centrally allocating emissions allowances, usually based on historical emissions
Greenhouse effect	An increase in the earth's temperature caused when the atmosphere transmits incoming solar radiation but blocks outgoing thermal radiation, primarily due to the presence of carbon dioxide and water vapour in the atmosphere
Greenhouse gas	An atmospheric gas that has the ability to absorb infrared radiation, contributing to the greenhouse effect (*e.g.* water vapour, carbon dioxide, methane)
Heat exchange	The transfer of energy between two substances at different temperatures, providing required heating or cooling
Heavy metals	Metallic elements with high atomic weights that can damage living things at low concentrations and tend to accumulate in the food chain (*e.g.* mercury, chromium, cadmium, arsenic, and lead)
Hot air	Emissions reductions against a target that occur without any dedicated abatement actions (*e.g.* due to economic downturn or prior legislation)

Hydrolysis	Reaction of a chemical compound with water
Hydroxyl radical	A highly reactive molecule containing one oxygen and one hydrogen atom responsible for the removal of many trace pollutants from the atmosphere
Indirect emissions	Emissions that result from the activity of an entity but are produced by a source external to the entity. For example, emissions occur because households use electricity, but the source of the emissions is a power station, not the house
JI	Joint Implementation is a mechanism of the Kyoto Protocol where a developed country can receive carbon credits when it helps to finance projects that reduce net emissions in another developed country (including countries with economies in transition)
Leachate	A liquid that results from water collecting contaminants as it trickles through wastes, agricultural pesticides or fertilizers and may result in hazardous substances entering surface water, groundwater or soil
Lifetime	The approximate amount of time a gas is present in the atmosphere before being removed from the atmosphere by conversion to another chemical compound or via a sink
Liquid market	A market where buying and selling can be accomplished with ease due to the presence of a large number of interested buyers and sellers prepared to trade substantial quantities at small price differences
Liquidity	The ease with which an asset can be converted to cash
Methanogenesis	The production of methane and carbon dioxide by biological processes carried out by single-celled micro-organisms called methanogens
Methanogenic	Methanogenic micro-organisms produce methane and carbon dioxide by the fermentation of simple organic compounds or the oxidation of hydrogen under anaerobic conditions
Methanotroph	An aerobic bacterium with the ability to utilise methane as sole carbon and energy source
Mitigation	Steps taken to avoid or minimise a negative environmental impact. This might include minimising, rectifying, reducing or compensating for the impact
Montreal Protocol	An international agreement to limit further damage to the ozone layer by drastically reducing the production and consumption of ozone-depleting substances (*e.g.* chlorofluorocarbons, halons, carbon tetrachloride). The treaty was signed in 1987 and substantially amended in 1990
Natural Gas STAR Programme	A USA voluntary initiative which aims to encourage natural gas companies to adopt 'best management practices' that can profitably reduce emissions of methane
Perturbation lifetime	A measure of the lifetime of a gas that includes its influence on other atmospheric species that occurs during its physical lifetime.

Potency (of a greenhouse gas)	The capacity of a gas to absorb and radiate heat energy over a specified period of time
Radiative forcing	A change, over time, in the balance between incoming solar radiation and outgoing infrared radiation, due to natural or anthropogenic causes. Positive radiative forcing warms the earth's surface whilst negative forcing cools
Recycling	The series of activities by which waste materials are collected, sorted, processed and converted into raw materials for use in the manufacture of new products
Renewable energy	Energy obtained from sources which are essentially inexhaustible. Renewable sources include hydroelectric power, wood (biomass), geothermal, wind, photovoltaic and some waste
Ruminant	An animal that chews its cud, has even-toed hooves and a multi-chambered stomach (*e.g.* cattle, sheep, goats, deer)
Termite	A soft-bodied ant-like insect which feeds on wood
Volatile organic compounds	Hydrocarbon based compounds that evaporate rapidly at ambient temperatures. These chemicals are often used as solvents and many are hazardous air pollutants such as benzene
Wetlands	Areas that are inundated or saturated by surface water or ground water at a frequency and duration sufficient enough to support vegetation adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, fens, bogs and similar areas

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Appendix 1: The atmospheric chemistry of methane

Tropospheric oxidation

The predominant mechanism for removal of methane from the earth's atmosphere is oxidation within the troposphere by the hydroxyl (OH) radical. The hydroxyl radical is responsible for the breakdown and removal of a host of trace gases, including methane, and for this reason is known as the 'cleanser of the atmosphere'. In essence, atmospheric OH effects a low temperature combustion of 'fuels', such as methane and other hydrocarbon species, by oxidising CH_4 to CO_2, as would happen if methane were burned.

The chemistry of methane in the troposphere is very simple as it only reacts with the hydroxyl radical and no other species. Methane is moderately chemically inert and even the reaction with OH is slow compared to other related hydrocarbons. However, whilst the reaction of CH_4 and OH is in itself simple, the network of inter-related chain reactions makes the bigger picture somewhat more complex. The removal of CH_4 from the atmosphere is intrinsically tied up with the chemistry of other species, notably the hydroxyl radical, carbon monoxide (CO), ozone (O_3) and oxides of nitrogen (NO & NO_2, termed NO_x). Carbon monoxide and the nitrogen oxides are known as 'indirect' greenhouse gases because, although they are not active greenhouse gases in themselves, they strongly affect the concentrations of the major greenhouse gases, such as CH_4, by either increasing their lifetimes or controlling O_3 and OH concentrations.

The process of tropospheric oxidation of methane is complex, with numerous feedback loops, as shown in Figure 23. Methane reacts with hydroxyl to form the methyl radical (CH_3) and water. The methyl radical undergoes further reactions to form either methyl hydroperoxide (CH_3OOH) or formaldehyde (HCHO). Both these species are soluble in water vapour and can be removed from the atmosphere as rain. Formaldehyde can also decompose in light to produce carbon monoxide (CO).

The slowest step of the reaction overall, and therefore the step that governs the speed of the entire reaction scheme, is the initial reaction between CH_4 and OH. The rate of removal of methane from the atmosphere is dependent on both the concentration of methane in the atmosphere and the concentration of the hydroxyl radical. An increase in methane concentration results in an increased rate of removal from the atmosphere, assuming OH concentration remains constant. However, because of feedbacks in the above reaction

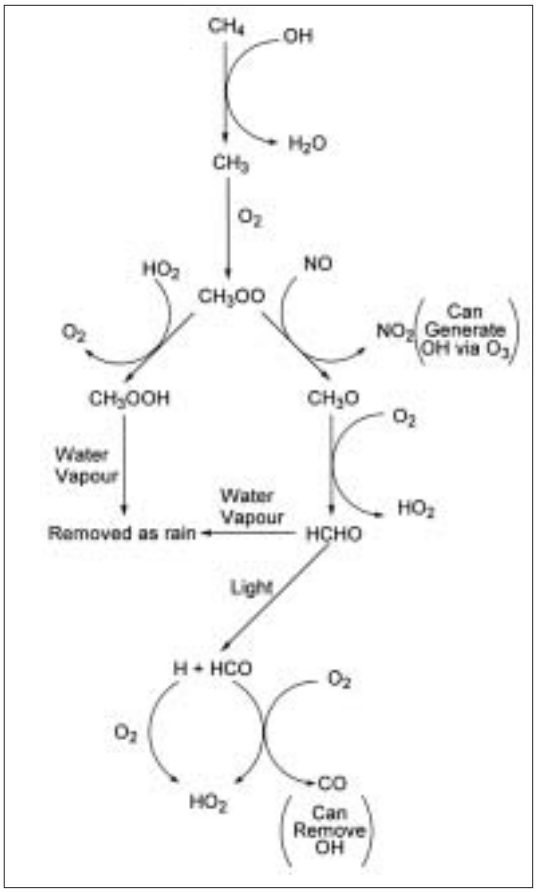

Figure 23: Oxidation of methane in the troposphere

scheme and other reactions, the OH concentration does not remain constant.

The initial reaction between CH_4 and OH removes one OH radical from the atmosphere for every CH_4 oxidised. Further steps in the reaction sequence generate NO_2, which can create OH radicals, and CO, which can remove them. Overall, the influence of CO is the more important and so the reaction scheme results in a net removal of OH radicals. An increase in CH_4 concentration will therefore remove OH from the atmosphere and thereby slow its own removal. This increases the atmospheric lifetime and subsequent environmental impact of CH_4. With methane emissions predicted to continue increasing, the lifetime of CH_4 in the atmosphere and therefore its Global Warming Potential (GWP) is predicted to increase over the coming years.

Role of the hydroxyl radical

The lifetime of methane is strongly tied to the chemistry and abundance of the hydroxyl radical, OH. Whilst feedback loops in the oxidation of CH_4 affect the concentration of OH in the atmosphere, the influence of the so-called indirect greenhouse gases CO and NO_x is much more pronounced. The chemistry of these species and their influence on OH concentrations in the troposphere is a major factor in the rate of removal of CH_4 from the atmosphere. Sources and sinks of the hydroxyl radical are shown in Figure 24.

Ozone is the main precursor of the hydroxyl radical and is the ultimate source of all oxidising reactions in the troposphere. Approximately 10% of ozone in the atmosphere resides in the troposphere, generated by the action of light on NO_2 and molecular oxygen (O_2), or transferred from the stratosphere. The relative importance of these two formation pathways is still a matter of some debate, although it is now generally agreed that the two sources are approximately equal.[27] Increased anthropogenic NO_x emissions will increase tropospheric ozone concentrations and therefore reduce CH_4 concentrations in the troposphere, at the expense of air quality.

Depletion of the ozone layer in the stratosphere will reduce the amount of ozone transferred into the troposphere but will also allow more light through, thereby increasing O_3 production in the troposphere from NO_2.

Ozone decomposes in light (and in doing so absorbs harmful uv radiation) and splits into molecular oxygen and an oxygen atom. The oxygen atom is electronically excited and hence highly reactive (denoted by O*). This species can abstract a hydrogen atom from water yielding two hydroxyl radicals. It is important to note that this process requires light and so OH concentration in the atmosphere shows daily, seasonal and spatial variations in concentration. The rate of hydroxyl production is also dependent on atmospheric water vapour concentration.

As well as the important role OH plays in initiating oxidation chains that remove methane from the atmosphere, it similarly removes other volatile organic compounds (VOCs) and nitrogen dioxide from the atmosphere. Other trace

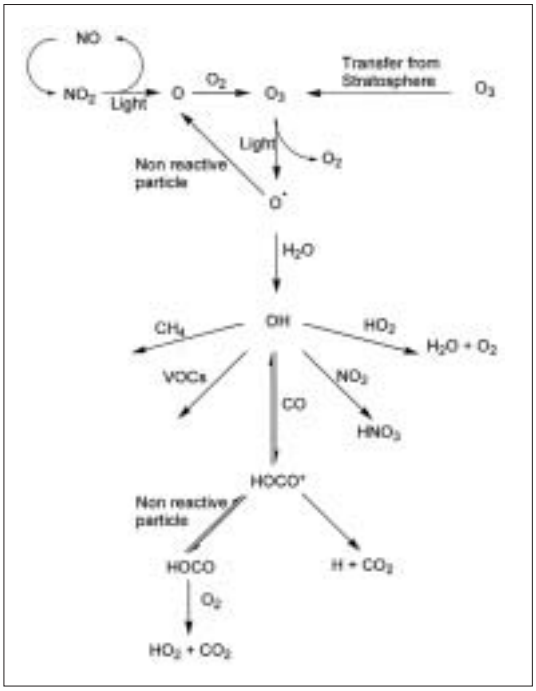

Figure 24: Sources and sinks of the hydroxyl radical

species, such as HO_2, can also be removed by reaction with the OH radical. However, the main reaction that affects the concentration of OH in the atmosphere is the reaction with carbon monoxide, CO. This reaction is much more rapid than the reaction between CH_4 and OH, and CO concentrations are comparatively high. This pathway is a significant mechanism for reducing OH concentrations in the atmosphere and subsequently reducing the rate of methane removal from the troposphere. Approximately 50% of CO in the troposphere is derived from oxidation of methane and other VOCs, so an increase in methane concentration causes an increase in CO concentration which will in turn decrease the rate at which OH removes methane. These feedback loops are accounted for in the perturbation lifetime of 12 years for CH_4. However, increased anthropogenic production rates of CO have the potential to throw this system out of balance.

Stratospheric oxidation

Some of the methane present in the troposphere passes into the stratosphere. Approximately 40 Mt of CH_4 are oxidised in the stratosphere, representing around 7% of all CH_4 removal. The chemistry of methane in the lower stratosphere is identical to that in the troposphere, with OH radicals oxidising CH_4 in the same manner. Indeed, oxidation of methane to CO_2 and water is the source of approximately 50% of stratospheric water vapour.

In the upper stratosphere, methane decomposition can be initiated in two other ways; by reaction with chlorine radicals or excited oxygen atoms. Ultraviolet light, which has high intensities in the stratosphere, causes the dissociation of a carbon chlorine bond, releasing a chlorine radical.

$$CH_3Cl \xrightarrow{\text{Light}} CH_3 + Cl$$

The chlorine radical may then react with methane forming a methyl radical and hydrogen chloride.

$$Cl\ CH_4 \longrightarrow CH_3 + HCl$$

Alternatively, uv light also causes the dissociation of ozone to yield an oxygen molecule and an electronically excited (highly reactive) oxygen atom (O*).

$$O_3 \xrightarrow{\text{Light}} O_3 + O^*$$

The excited oxygen atom can also initiate the oxidation of methane, yielding a methyl radical and a hydroxyl radical.

$$O^* \longrightarrow CH_3 + OH$$

The reaction of CH_4 with either Cl or O* yields a methyl radical, which undergoes subsequent reactions to form CO_2 and H_2O in the same manner as in the troposphere (Figure 23). The only difference between the chemistry of methane in the upper stratosphere compared to the troposphere and lower stratosphere lies in the possibility of different chain initiation steps that do not rely on the hydroxyl radical.

The main sources of chlorine radicals are methyl chloride (CH_3Cl), trichlorofluoromethane ($CFCl_3$), dichlorodifluoromethane (CF_2Cl_2), carbon tetrachloride (CCl_4) and 1,1,1–trichloroethane (CH_3CCl_3). Of these, only methyl chloride is of natural origin, the others are all man-made compounds. These CFCs are responsible for the thinning of the ozone layer in polar regions and emissions are now strictly controlled under the Montreal Protocol. However, these species are long lived in the atmosphere and will continue to exist in relatively high concentrations over the course of the next century.

Uptake by soils

Approximately 30 Mt of CH_4 are removed from the atmosphere annually through uptake by soils. Soils contain populations of methanotrophic bacteria that can oxidise methane. These bacteria are of two sorts: those that carry out high affinity oxidation and those that carry out low affinity oxidation.

'High affinity oxidation' is where

methanotrophic bacteria consume methane that is in low concentrations, close to that of the atmosphere (<12ppm). It is this process that acts as an atmospheric sink for CH_4 from the global atmospheric burden. The bacteria favour upland soils, in particular forest soils. The bacteria responsible for high affinity oxidation processes remain largely unknown. It is known, however, that high ammonium concentrations in soils lead to a loss of methanotrophic bacteria and a subsequent reduction in the rate of methane oxidation. The use of artificial fertilisers containing ammonia is therefore detrimental to the uptake of CH_4.

'Low affinity oxidation' occurs where methanotrophic bacteria operate under methane concentrations considerably higher than in the atmosphere. These bacteria exist in wetlands, paddy fields and landfill site caps where there are high methane concentrations due to the presence of methanogenic bacteria. Low affinity oxidation does not remove CH_4 from the atmosphere and is not included in the value of 30 Mt CH_4 taken up by soils annually. However, because methanotrophic bacteria working under low affinity oxidation conditions absorb up to 90% of the CH_4 produced by methanogenic bacteria in the same environment, they significantly reduce CH_4 emissions from these sources. These bacteria are also highly susceptible to anthropogenic influences on their habitat, like land and water management, use of chemical fertilisers and pesticides and soil acidity. Changes in CH_4 emissions from paddy fields and other wetlands may be due to changes in the balance between methanogenic and methanotrophic bacteria in the environment.

Increases in atmospheric CH_4 concentrations may inhibit the microbial uptake of CH_4 in soils via a process that couples soil methane and ammonia. However, the effect is expected to be small, since the global sink strength for microbial uptake of CH_4 by soils is only 30 Mt/yr.

Notes

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