

methane uk

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Biffaward programme on sustainable resource use

Objectives

This report forms part of the Biffaward Programme on Sustainable Resource Use. The aim of this programme is to provide accessible, well-researched information about the flows of different resources through the UK economy based either singly, or on a combination of regions, material streams or industry sectors.

Background

Information about material resource flows through the UK economy is of fundamental importance to the cost-effective management of resource flows, especially at the stage when the resources become 'waste'.

In order to maximise the Programme's full potential, data will be generated and classified in ways that are both consistent with each other, and with the methodologies of the other generators of resource flow/waste management data.

In addition to the projects having their own means of dissemination to their own constituencies, their data and information will be gathered together in a common format to facilitate policy making at corporate, regional and national levels.

Mass balance UK

The methane uk project is not strictly a mass balance project, as it deals with post-disposal generation of methane from landfill sites as well as that from agriculture and fossil fuel sources. However, it complements existing publications in the Sustainable Resource Use series including Carbon UK (2002). More than 30 different mass balance projects have been funded by Biffaward. For more information on the Mass Balance UK programme please visit www.massbalance.org

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Contents

Figures	4	6 Agriculture	
Tables	4	6.1 How is methane produced?	52
Executive summary	5	6.2 Mitigating emissions from livestock	53
1 Methane and climate change		6.3 Mitigating emissions from manure management	55
1.1 Climate change and the role of greenhouse gases	6	6.4 Existing EU and UK policy	57
1.2 Why methane?	9	6.5 Recommendations	58
1.3 International policy context	10	7 Oil and gas sector	
1.4 UK policy context	12	7.1 Introduction	60
1.5 Role of methane emissions reductions	12	7.2 Sources of methane	60
2 Climate science of methane		7.3 Mitigating methane emissions	61
2.1 Introduction	14	7.4 Existing UK policies	61
2.2 Methane sources	14	7.5 Recommendations	62
2.3 Methane sinks	18	8 Coal mine methane	
2.4 Methane in the atmosphere	20	8.1 Production	64
3 Methane emissions trading		8.2 Mitigation	65
3.1 Emissions trading concept	24	8.3 Current policy	68
3.2 Emissions trading schemes	26	8.4 Recommendations	69
3.3 Review of the UK ETS	29	9 Discussion and conclusions	
3.4 Conclusions	30	9.1 Importance of methane	72
4 Methane in the UK		9.2 Disparity of methane sources	72
4.1 UK methane sources	32	9.3 Methane trading	72
4.2 Historical trends	32	9.4 Recommendations	74
4.3 Breakdown by region	33	9.5 Conclusions	74
4.4 Data uncertainties	34	Glossary	78
4.5 UK greenhouse gas emissions	35	References	83
5 Waste and landfill		Appendix I The atmospheric chemistry of methane	89
5.1 Methane from landfill	37		
5.2 Landfill in the UK	39		
5.3 Methane capture	41		
5.4 Alternatives to landfill	45		
5.5 Recommendations	49		

Figures and tables

Figure 1 Infra-red radiation is trapped within the earth's atmosphere by trace greenhouse gases	9	Table 1 Global Warming Potentials of the 'basket' of six gases	11
Figure 2 Global average surface temperature since 1860	10	Table 2 Sources of global methane emissions	16
Figure 3 Historical and projected atmospheric concentrations of carbon dioxide	11	Table 3 Emissions of methane (Mt) by source as quantified by different academic studies	17
Figure 4 Global methane cycle	17	Table 4 Sinks of methane	21
Figure 5 A representative distribution of worldwide anthropogenic and natural sources of methane	19	Table 5 Radiative forcing of selected greenhouse gases	23
Figure 6 Relative concentration of methane in the atmosphere	22	Table 6 Global Warming Potentials for the greenhouse gas 'basket'	25
Figure 7 Radiative forcing of methane and carbon dioxide	25	Table 7 Comparison between the UK and EU Emissions Trading Schemes	31
Figure 8 Effect of emissions cessation (a) and gradual reduction (b) on atmospheric concentration	27	Table 8 UK methane emissions from 1990-2002 (Mt CH ₄)	37
Figure 9 Comparison of (a) regulated approach & (b) market trading approach	29	Table 9 Regional breakdown of methane and total GHG generation, UK, 2000	37
Figure 10 UK ETS carbon prices, 2002-4	34	Table 10 UK GHG emissions 1990-2002 (MtCO ₂ e)	39
Figure 11 UK sources of methane, 2002	36	Table 11 Methane formation in landfill	43
Figure 12 Long term trends in methane emissions, UK	37	Table 12 The waste hierarchy and options for dealing with biodegradable matter	45
Figure 13 Methane emissions by source and region, 2000	39	Table 13 Contracts under Renewables Obligation, December 2001	50
Figure 14 UK greenhouse gas emissions, 1990-2002	41	Table 14 Financial incentives for electricity generation from waste streams	53
Figure 15 Estimated annual waste by sector (by mass)	43	Table 15 Methane produced by enteric fermentation and manure management (kg methane per head per year)	57
Figure 16 Disposal methods of municipal waste, England, 1996-2003	46	Table 16 Potential for methane trading in each sector	80
Figure 17 Enteric fermentation in ruminant mammals	59	Table 17 Disparity of methane sources and appropriate mitigation measures	81
Figure 18 Gas consumption by sector, UK, 1970-2003	67		
Figure 19 North Sea Oil and Gas Fields	68		
Figure 20 Coal fields in the UK	72		
Figure 21 Recovery of methane from abandoned wells	74		
Figure 22 Thermal flow reversal reactor	75		
Figure 23 Oxidation of methane in the troposphere	101		
Figure 24 Sources and sinks of the hydroxyl radical	102		

Executive summary

Methane is an extremely powerful greenhouse gas, particularly in the short-term (less than 12 years). It becomes more long-lived and damaging as the concentrations in the atmosphere increase, by altering the balance of the atmospheric chemical processes. These two important considerations for methane mitigation policy indicate that the focus should be on immediate reductions.

The main sources of methane in the UK related to human activity are landfill, coal mines, ruminants and their manure, and leakages from the natural gas system.

In landfill sites, methane results from the breakdown of biomass derivatives (*e.g.* tea leaves, paper) over a period of at least 15 to 20 years. Up to 85% of the methane generated can be captured and then burned to produce electricity which qualifies for Renewable Obligation Certificates – an economically profitable process that provides sufficient incentive to improve methane capture. The remaining uncaptured methane will still escape to the atmosphere. The EU Landfill Directive requires the amount of biodegradable waste going to landfill in the UK to be reduced to 35% by 2020, so the quantity of methane produced will decrease over time.

Coal mine methane comes from both active and abandoned mines, but only the former is accounted for in greenhouse gas inventories. The latter represents a potentially significant figure that is ignored by the present system although DEFRA is close to completing an inventory. This form of methane release should no longer be ignored. Technologies for capturing methane from deep mines exist but lack the necessary financial drivers to encourage implementation in the UK. There are no current policies to encourage capture for energy recovery and it is recommended that these should be developed by the Government.

There are opportunities to process animal manure in anaerobic digesters and thus trap the methane for use in electricity generation that qualifies for ROCs. This avenue is advocated for

greater encouragement. Policies to reduce the amount of methane produced by sheep and cows (the source of 90% of agricultural methane emissions) – for instance injections, different feedstocks and preferential breeding – could meet consumer resistance and are not seen as a mainstream option. The Common Agricultural Policy is expected to reduce the present subsidy (£1.40 per day, per cow), which, along with consumer trends to less dairy and red meat consumption, is likely to have a gradual but persistent effect on UK demand and possibly production. Agricultural emissions have been slowly reducing and may continue to do so, but will remain the major source of methane in the UK.

The leakage of natural gas from the transmission and distribution system is poorly quantified but probably a substantial problem. Because of uncertainty about the numbers there can be no possibility of using reductions in a trading system. The policy emphasis has to be with Ofgem and regulation.

Methane trading is a viable option for reducing emissions in some sectors. Methane from active coal mines and gas and oil rigs has been successfully traded under the UK Emissions Trading Scheme. It is essential that this trading opportunity continues through incorporation of methane into the EU Emissions Trading Scheme in 2008, with interim policies to cover the two year gap after closure of the UK ETS in 2006.

These various programmes should be supported by a more imaginative framework that reflects the importance of achieving rapid methane reductions. Serious consideration must be given to the short-term influence of gases such as methane. A focus on emissions that have a strong, immediate effect on the climate would buy time for carbon dioxide reducing policies and technologies to become more effective and prevent methane from becoming more potent.

Methane and climate change



Methane (CH_4) is a colourless, odourless, tasteless gas, which is naturally present in the atmosphere and is the main component of the fossil fuel, natural gas. The importance of methane (CH_4) is second only to carbon dioxide (CO_2) in terms of overall contribution to human-induced climate change. Whilst methane exists in a far lower atmospheric concentration than carbon dioxide, it is a particularly powerful greenhouse gas, deemed responsible for around 20% of post-industrial global warming.¹ The relative potency and short atmospheric lifetime of the gas make efforts to reduce methane emissions an attractive climate change policy option. A unit reduction of one tonne of methane is deemed equivalent to a reduction of 23 tonnes of carbon dioxide.¹ Because of the relative potencies, mitigating methane emissions is often more cost effective than mitigating carbon dioxide emissions and is therefore an ideal method of achieving international and government set targets at minimum cost to the economy. It can also buy time for the development of carbon dioxide mitigation technologies not sufficiently advanced at present to be cost-effective.

So far, methane has played a pivotal role in efforts to meet the UK's greenhouse gas emission reduction target under the Kyoto Protocol, accounting for 30% of the overall greenhouse gas reduction between 1990 and 2002. However, much of this decrease in methane emissions has been serendipitous, being a result of a decline in

the UK coal industry and improved landfill cap technologies, rather than a result of targeted policy. In order to help mitigate climate change and be assured of meeting the Kyoto target and subsequent obligations, it is imperative that further methane emission reductions are both achieved and maintained in the long term. Identifying the most efficient way of reaching these goals, coupled with effective policies, must now be a priority. The question for policy makers is this – what is the easiest way of reducing our influence on the climate of our planet with minimal impact to individuals and minimum impact to the economy?

This report examines the major sources of methane in the UK, technologies for emissions abatement, current policies and future policy measures that could bring about lasting emissions reductions, with a particular focus on the potential for methane trading.

1.1 Climate change and the role of greenhouse gases

There is now widespread scientific consensus relating to the profound influence of human activity on the global climatic system, particularly through increased emissions of greenhouse gases in the post-industrial era. The effect on the global climate is already apparent and is likely to become more pronounced over the forthcoming decades.

What is the greenhouse effect?

The greenhouse effect is the term used to describe the warming mechanism provided by certain atmospheric gases. These are typically trace gases, known as greenhouse gases, which naturally make up about 1% of the atmosphere. Greenhouse gases are effective absorbers of infra-red radiation (heat), so the radiation emitted from the earth's surface cannot then escape into space (Figure 1). The net result is that the greenhouse gases trap energy inside the earth's atmosphere and maintain the earth's surface temperature at

Figure 1 : Infra-red radiation is trapped within the earth's atmosphere by trace greenhouse gases

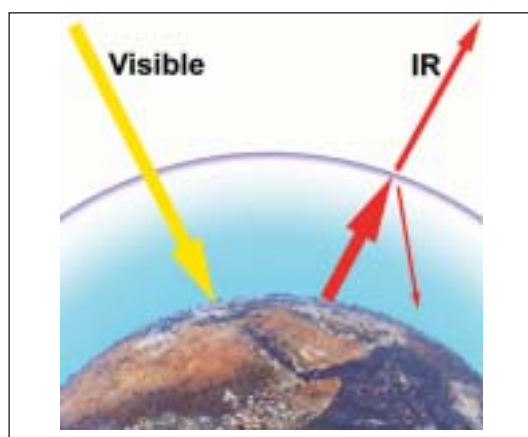
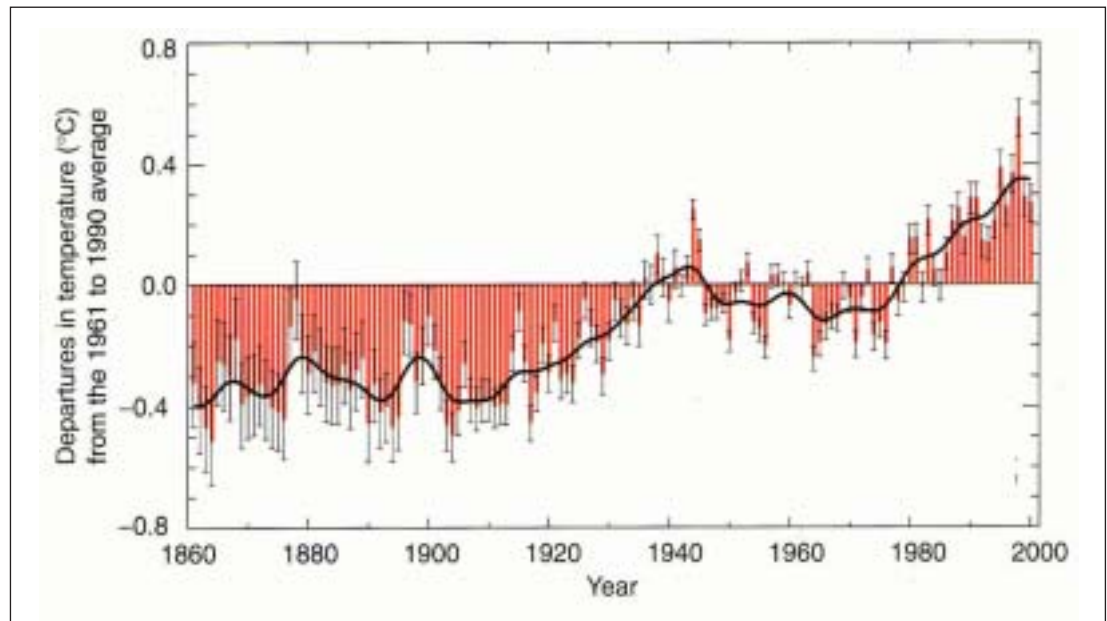


Figure 2 Global average surface temperature since 1860

Note: Bars are annual average, solid line is decadal average

Source: IPCC, 2001¹



approximately 30°C warmer than it would be were these trace gases not present. As such, the presence of greenhouse gases in the atmosphere is vital for our existence. Most notably, they maintain a moderate temperature where water can exist in liquid form – an important precondition for organic life.

The changing global climate

Climate science is extremely complex and whilst our current understanding is incomplete, it is advancing as modelling and monitoring improve. The most accurate picture of our understanding of the planet's atmosphere has been achieved through a 'consensus' of current knowledge under the Intergovernmental Panel on Climate Change (IPCC). This is a body established by the World Meteorological Organisation and United Nations Environment Programme to assess scientific, technical and socio-economic information relevant for the understanding of climate change, its potential impacts and options for adaptation and mitigation. It does not carry out its own research but collates information from peer-reviewed papers into a coherent whole. As such, the IPCC reports are seen as being as close to

definitive as our current understanding allows. The IPCC's Second Assessment Report of 1995² was instrumental in the development of the Kyoto Protocol and the Third Assessment Report¹ was published in 2001.

It is now widely acknowledged that the delicate natural equilibrium is being thrown out of balance. The IPCC reports that during the last century, global average surface temperature has increased by over 0.6°C¹. This is likely to be the largest temperature increase of any century during the last 1000 years and the implications are becoming increasingly apparent. It is very likely that the warming during the 20th century has contributed significantly to the observed sea level rise of 10 to 20 cm, through thermal expansion of seawater and widespread loss of land ice. Since the 1950s, the extent of spring and summer ice cover in the Northern Hemisphere has decreased by 10-15% and, since the 1960s, land snow cover has reduced by around 10%. Global warming is also linked to marked changes in precipitation regimes. The intensity and frequency of droughts in some parts of Asia and Africa have increased, whilst elsewhere, areas have become wetter and heavy precipitation



Figure 3 : Historical and projected atmospheric concentrations of carbon dioxide

Source: Global Commons Institute

events leading to flooding have become more commonplace.

The IPCC's Third Assessment Report² attributes 'most' of the observed warming over the last 50 years to human activity (anthropogenic emissions) and increased atmospheric concentrations of greenhouse gases (Figure 3), leading to an *enhanced greenhouse effect*.

Continued growth in greenhouse gas emissions is predicted to intensify climate change over the next century. In particular, global climate models predict that average surface temperature will increase by between 1.4 and 5.8°C between 1990 and 2100 based on a range of greenhouse gas emission scenarios. This is far in excess of the observed changes during the last century and consequently the knock-on effects for ice coverage, sea level rise and precipitation regimes are likely to be intensified.

Global warming and climate change

Climate change is the variability in the earth's climate, which is increasing as a result of global warming. However, the relationship between global warming and the impacts of climate change is complex: we cannot say that, for example in terms of livelihood or economic impacts, a 4°C temperature rise will be twice as harmful as a 2°C temperature rise.

Some climate impacts are directly related to the extent of the *temperature rise*; ice cover will reduce and sea levels will rise as temperature increases. For other climate impacts it is the *rate of temperature rise* that is the critical factor; ecosystems are capable of adapting to temperature rises, but only over suitably long timescales. The different greenhouse gases have different potencies and lifetimes and so affect the *extent* and *rate* of global warming in different ways. Methane is a peculiar case, being potent in



Flooding and flood management currently cost the UK around £2.2 billion per year

the short term yet short-lived, therefore predominantly affecting the *short-term rate of global warming*.

1.2 Why methane?

Anthropogenic emissions of greenhouse gases have caused substantial changes to our climate and will continue to do so over the course of the next century and beyond, if emissions are not stabilised, or preferably reduced.

The IPCC has identified a 'basket' of six greenhouse gases that contribute to anthropogenic climate change. These are carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), the chlorofluorocarbons (CFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF₆).

The Kyoto Protocol (Section 1.3) is a multi-gas abatement strategy, allowing reductions to be made in any of the six major greenhouse gases. Such multi-gas strategies have been shown to be cheaper than a single gas strategy.^{3,4} They are also politically less sensitive as they allow countries to choose their own pathway to an overall greenhouse gas (GHG) emission reduction, rather than having limits per gas imposed on them by an external body. This allows flexibility between different countries with different portfolios of GHG emissions. For example, countries with good renewable energy resources may wish to promote these resources and thereby reduce carbon dioxide emissions. Other countries may find it more effective to reduce methane emissions by altering waste management or agricultural practices.

Potency

Such multi-gas abatement strategies require a measure of the relative potency of the different gases. The Global Warming Potential (GWP) is the most commonly used parameter for this. Several different definitions of the GWP exist – by far the most common is the 100 year GWP, which is used in all international and government policies including the Kyoto Protocol (Table 1).

Table 1: Global Warming Potentials of the 'basket' of six gases

Gas	Global Warming Potential (100-year)	Lifetime (years)
CO ₂	1	5-200
CH ₄	23	12
N ₂ O	296	114
HFCs	12-12,000	0.3 - 260
PFCs	5,700-11,900	2,600-50,000
SF ₆	22,200	3,200

Source: IPCC 2001¹

It can be seen that on a 100-year timescale, one tonne of methane is 23 times more potent than one tonne of carbon dioxide. This makes methane an attractive option for greenhouse gas emission reductions because smaller reductions are necessary to achieve the same environmental goal. Methane is currently emitted in enough volume to make any reductions significant in terms of the overall GHG picture. Methane can be readily captured from localised sources such as landfill and coal mines. Furthermore, methane is a flammable gas with a high energy content which, once captured, can be used as a fuel with the added economic benefits of heat or electricity generation.

True potential

The Third Assessment Report provided revised GWP figures for a number of gases, notably increasing the relative potency of methane from 21, quoted in the Second Assessment Report, to 23. However, parties to the UNFCCC have agreed that the revised figures will not apply until the second commitment period (2013-2017). Therefore progress towards the original Kyoto targets set for 2008-2012 will continue to be calculated using GWP figures provided within the Second Assessment Report (*i.e.* a GWP of 21). Similarly, inventory submissions will continue to be based on old GWP figures throughout this period, according to the current reporting guidelines.⁵

For the remainder of this report, a GWP of 23 is used when referring to the current level of scientific understanding. However, a GWP of 21 is implied in all discussions relating to current policy concerned with emissions as reported under the UN Framework Convention on Climate Change guidelines (Section 1.3).

Lifetime

It is also worth noting that methane has a comparatively short lifetime in the atmosphere of just 12 years, compared with up to 200 years for carbon dioxide. This means that reductions in emissions are rapidly turned into atmospheric concentration reductions. Gases with a longer lifetime reach higher atmospheric concentrations and experience a longer lag between emissions reductions and decreased atmospheric concentrations. Reducing emissions of short-lifetime potent gases such as methane is therefore a valuable means of rapidly slowing global temperature rise. This gives reduction of methane emissions a high economic value (perhaps even greater than reflected in the GWP of 23) as they are effective at slowing the rate of global warming. They are also likely to be even more important at some point in the future should the effects of climate change become critical and fast-acting measures need to be adopted.^{6,7}

1.3 International policy context

The international community originally drew attention to the link between climate change and human activities at First World Climate Conference in 1979. Extensive scientific research, international debate and a series of intergovernmental conferences followed, culminating in 1992 with the production of the UN Framework Convention on Climate Change (UNFCCC).

The UN Framework Convention on Climate Change

The UNFCCC entered into force in 1994. Currently 181 governments and the European Union are party to the Convention. Its ‘ultimate objective’ is to stabilise atmospheric concentrations of greenhouse gases at safe levels, although it does not assess what these levels are. The signatories are required to submit regular national communications, including information on strategies for mitigating and adapting to climate change along with detailed greenhouse gas emission inventories.

The atmospheric concentration of any greenhouse gas is determined by the balance between emissions from sources of the gas and removals by sinks. At present, emission rates exceed rates of removal and consequently atmospheric concentrations of greenhouse gases continue to rise. The IPCC report that in order to stabilise carbon dioxide emissions at 450, 650 or 1000 ppm, global anthropogenic emissions would need to drop below 1990 levels within a few decades, about a century, or about two centuries, respectively, and continue to decrease steadily thereafter.

Even if emissions are stabilised now, global average surface temperature is expected to continue to rise for centuries to come. However, by stabilising emissions as quickly as possible, the temperature increase could be reduced from several degrees per century to tenths of a degree. The lower the level at which emissions are stabilised, the smaller the increase in temperature expected. Furthermore, by acting on the more short-lived methane, the global temperature increase can be minimised more rapidly.

The Kyoto Protocol

The ultimate goal of the UNFCCC is the “stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system”. In 1997, the adoption of the Kyoto Protocol went one step further towards this

Renewable energy currently accounts for around 3% of UK electricity generation



goal, strengthening the commitments under the UNFCCC by providing legally binding emission reduction targets for developed countries (the so-called Annex I countries). Targets for individual countries were established through negotiation, although in total are equivalent to a 5.2% reduction from 1990 levels by the first commitment period of 2010 (defined as the average emissions for the period 2008-2012, to cope with anomalous years).

It is widely acknowledged that these 5.2% targets set by the Kyoto Protocol are not stringent enough to avert potentially catastrophic climate change, but they are a major step in the right direction. Crucially, it is envisaged that the Kyoto Protocol will entail further five-year commitment periods, with progressively stricter emission reduction targets. The second commitment period is scheduled for 2013-2017, with negotiations of targets beginning in 2005.

The Kyoto Protocol will finally become legally binding on 16 February 2005, following ratification of the treaty by Russia in November 2004.

How will the Kyoto Protocol work?

To alleviate the adverse economic effects of comprehensive limits on greenhouse gas emissions, three flexibility mechanisms, also referred to as the Kyoto mechanisms, were included in the Kyoto Protocol: International Emissions Trading (IET), Joint Implementation (JI) and the Clean Development Mechanism (CDM). The purpose of these mechanisms is to allow

industrialised countries to meet their targets through trading emission allowances with each other and gaining credits for emission-curb projects abroad.

The central strategy to curb greenhouse gas emissions is that of emissions trading through the IET. Emissions trading involves the trading of permits to emit greenhouse as if they were conventional commodities such as gold or oil. It allows emissions reductions to be achieved at minimal cost to the economy, by allowing over-emission from those who cannot meet targets cheaply to be offset by under-emission from those who can mitigate at low cost. Emissions trading, and the role that methane might play within such a scheme, is discussed in greater detail in Chapter 3. While implementation of the three flexibility mechanisms at international level will become possible only once the Kyoto Protocol comes into force, emissions trading of greenhouse gases has already begun at a domestic level in the UK and in other countries such as Denmark. The EU has already put in place an EU-wide trading scheme, due to start in 2005.

Joint Implementation and the Clean Development Mechanism are designed to provide flexibility for countries to meet part of their Kyoto targets by taking advantage of opportunities to reduce greenhouse gas emissions in other countries at lower cost than at home. These two mechanisms are project-based and allow the generation of credits when projects achieve emission reductions that are additional to that which would have occurred in the absence of the project. Joint Implementation refers to projects in countries that also have emission targets, whereas the Clean Development Mechanism refers to projects in developing countries with no targets. The rationale is that, for the global environment, where the emission reduction occurs is of secondary importance provided that real emission reductions are achieved. In order to promote participation by corporate investors, this should be allowed to occur where costs are lowest.

Addressing climate change in the UK

The UK was amongst the first nations to ratify the Kyoto Protocol. Under burden sharing agreements within the EU, the UK has committed to an emissions reduction target of 12.5%, relative to a 1990 baseline, on the 'basket' of six greenhouse gases by 2008-2012. This target can be met through reductions in all or any of the basket of six gases, allowing flexibility in the choice of policy options, and is calculated in CO₂ equivalent terms.

The Energy White Paper, published in February 2003, has positioned the UK at the forefront of international efforts to tackle climate change, with an ambitious target of a 60% reduction in carbon dioxide emissions by 2050.⁸ The UK Government is working to encourage the international community to adopt similar targets with the launch of its International Energy Strategy in October 2004.⁹

1.4 UK policy context

There are certain UK policies which have played a role in encouraging methane emissions reductions, either directly or indirectly.

Renewables targets

Under the EU Renewables Directive, which came into force in October 2001, the UK has adopted a target of 10% of UK electricity consumption by 2010 to come from renewable sources. In previous years wastes have been included with renewables, but from 2004, the international definition of total renewables has been adopted which excludes non-biodegradable wastes.¹⁰

Renewables Obligation

The Renewables Obligation, introduced in April 2002, is the key policy measure to help achieve the UK's renewable energy targets and will remain in place until 2027, with yearly targets set up until 2011. It requires all licensed electricity

suppliers in England and Wales to supply a specific proportion of their electricity from renewables, evidenced via a system of Renewables Obligation Certificates (ROCs).

ROCs are issued to accredited generators and may be traded separately from the electricity to which they relate, allowing suppliers who have failed to reach the target to purchase certificates from those suppliers that have surpassed their Obligation requirements. Renewable technologies eligible for ROCs include wind, landfill gas and incineration of biomass, amongst others. Incineration and co-firing of mixed waste are excluded. ROCs are one of the key economic drivers in the UK for encouraging investment in methane mitigation.

Climate Change Levy

The Climate Change Levy (CCL) was introduced in April 2001 as a tax on electricity supplied to non-domestic customers in the UK. Intensive users of energy are able to join Climate Change Levy Agreements, helping to mitigate the effects of this tax. Under these agreements, businesses that accept and subsequently meet energy reduction targets will receive an 80% levy discount until the year 2013. Electricity from qualifying renewable sources, such as solar and wind power, is exempt from the Levy and eligible for Levy Exemption Certificates (LECs). Electricity from some energy from waste schemes is not exempt.

1.5 Role of methane emissions reductions

The importance of methane in meeting the UK's Kyoto target cannot be understated. So far, methane emissions have fallen by 43% between 1990 and 2002 (Section 4.5), equivalent to 30% of the UK's total greenhouse gas emission reductions. The proportional contribution of methane to total emission reductions is expected to increase, with UK Government baseline

projections aimed at halving methane emissions by 2020.¹¹

Emphasis on methane emission reduction could pave the way for commercial opportunities and enhanced competitiveness, with increased efficiency and technological developments in methane mitigation, capture and utilization forming an integral component of a lower carbon economy. Methane emission reduction is also particularly apposite to improved safety, owing to the flammable and explosive nature of the gas. Furthermore, the high energy content of methane makes its combustion for energy recovery highly desirable. Utilisation of methane to generate electricity or heat, producing the less potent carbon dioxide, can offset emissions from more carbon-intensive coal or oil powered generators.

On a global basis, the benefits of methane emission reductions in terms of climate change abatement may be even more profound. The short lifetime and relative potency of methane in the atmosphere mean that the benefits of emission reductions are quickly apparent. Investment in methane abatement technologies would buy time for the development of cheaper carbon dioxide mitigation technologies, especially new renewable energy technologies. Large cuts in methane emissions could potentially avert or delay climate change in the short term, providing the much needed time for carbon dioxide mitigation policies to be implemented and their effects observed in the atmosphere.

Climate science of methane



2.1 Introduction

Methane is the most abundant reactive trace gas in the atmosphere and arises from both natural and anthropogenic sources. It is a valuable gas and is usable at a wide range of concentrations, down to 5%. In concentrated form it is flammable, representing an explosion risk in confined conditions.

The global atmospheric burden of methane (in 1998) was 4850 Mt(CH₄), equivalent to an average concentration of 1745 parts per billion (ppb). The global methane budget can be modelled by simply considering emissions as increasing the atmospheric burden of methane, with sinks removing methane from the atmosphere – the methane cycle. The concentration of methane in the atmosphere is thought to be increasing at a rate of 22 Mt/yr, due to the imbalance between estimated annual global emissions of 598 Mt and removals of 576 Mt (Figure 4).¹

It is therefore important to reduce global emissions to such a level that they are outweighed by methane sinks, so that the concentration of methane in the atmosphere decreases and its subsequent warming effect is reduced. A reduction of global emissions by just 22 Mt per year would result in stabilisation of methane concentrations in the atmosphere. Such a reduction represents just 3.6% of total methane emissions, or 6.1% of anthropogenic emissions. Such small reductions should be attainable. Obtaining a reduction in atmospheric methane concentrations would provide an encouraging example in the fight against global warming.

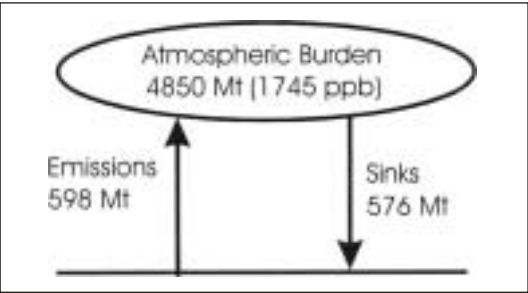


Figure 4: Global methane cycle

2.2 Methane sources

Methane is emitted from a range of natural and anthropogenic (relating to human activity) sources as a result of the anaerobic decomposition of organic matter, land use changes and fossil fuel related emissions (Table 2).

Table 2: Sources of global methane emissions

<i>Natural</i>	<i>Anthropogenic</i>
Wetlands	Agricultural livestock
Termite activity	Rice cultivation
Oceans	Waste practices
	Coal mining
	Natural gas distribution
	Biomass burning

Whilst the major sources of atmospheric methane have been identified, quantifying their individual contributions to global emissions has proved



Wetlands are areas of marsh, fen, peatland and water, representing approximately 6% of the world's land surface

Table 3: Emissions of methane (Mt) by source as quantified by different academic studies

Source	<i>Fung et al.¹⁴</i>	<i>Hein et al.¹⁵</i>	<i>Lelieveld et al.¹⁶</i>	<i>Houweling et al.¹⁷</i>	<i>Mosier et al.¹⁸</i>	<i>Olivier et al.¹⁹</i>	<i>Cao et al.²⁰</i>	SAR ²	TAR ¹
Natural									
Wetlands	115	237	225	145			92		
Termites	20		20	20					
Ocean	10		15	15					
Hydrates	5		10						
Anthropogenic									
Energy	75	97	110	89		109			
Landfill	40	35	40	73		36			
Ruminants	80	90	115	93	80	93			
Waste Treatment			25		14				
Rice Agriculture	100	88			25-54	60	53		
Biomass	55	40	40	40	34	23			
Other				20	15				
TOTAL	500	587	600					597	598

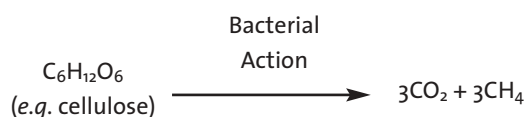
Source: IPCC, 2001¹

problematic.^{12,13} For many sources, emissions are highly variable in space and time. For instance, emissions from most types of wetlands can vary by a few orders of magnitude over just a few metres.¹

Based on a range of studies, the IPCC¹ estimates that global emissions of methane are around 598 Mt per year, but does not provide a definitive breakdown of CH₄ emissions by source. Other studies have attempted to classify this, but there are a wide range of estimates and definitions used for each sector (Table 3). This lack of accuracy and definitive emissions figures is a serious handicap to the design of practical policy and trading schemes.¹³

The role of bacteria

There are two classes of bacteria actively involved in the methane cycle. Methanogenic bacteria generate methane by breaking down organic matter in the absence of oxygen (anaerobically), releasing carbon dioxide and methane according to the reaction:



Conversely, methanotrophic bacteria oxidise methane to carbon dioxide. Methanotrophic bacteria are of two sorts; low affinity oxidation, where methanotrophs oxidise high concentrations of methane at the source of production (usually a population of methanogenic bacteria), and high affinity oxidation, which can oxidise methane present at atmospheric concentrations.

Natural sources

The main natural sources of methane are wetlands, termites and oceans. Wetlands are by far the largest source, accounting for 30% of total emissions (Figure 5), with methane being produced from the anaerobic decomposition of organic matter covered by water. Because this process involves the action of bacteria, the rate of methane production is strongly temperature dependent. Maximum methane production is experienced at temperatures between 37 and 45°C and so future increases in global temperature may enhance methane production from wetlands, thereby reinforcing the greenhouse effect.

Methane is also produced by the digestive processes of termites, resulting in the generation of around 20 Mt per year – approximately 5% of world methane emissions. This value is unlikely to change as termite populations are not expanding despite greater availability of biomass due to deforestation.²² Methane emissions from termites should be treated as a significant, but background, source that is likely to remain constant.

Oceans contribute approximately 2% to global methane emissions. The methane is produced by methanogenic bacteria within sinking particles in

surface waters. The production of methane from oceans is spatially dependent, with much methane arising from methanogenesis in marine sediments, particularly in nutrient rich areas such as estuaries. There is also an anthropogenic component to ocean emissions, with bacterial populations being increased by high nutrient levels from agricultural fertiliser run-off and waste treatment effluents.

Anthropogenic sources

Approximately 60% of emissions are related to human activities. The key anthropogenic sources of methane include fossil fuels, agriculture, landfill and the burning of biomass. Methane emissions arising from the fossil fuel industry form the largest anthropogenic source of methane, estimated to be between 80 and 100 Mt per year. The main sources of fossil fuel-related methane emissions are the release of natural gas from coal mining and leakage from gas processing and distribution pipes. Pockets of methane that have been trapped between layers of coal during its formation and methane within the coal itself are released once the coal is mined.

Agricultural practices also result in significant methane emissions, the two major sectors being rice production and the rearing of livestock. Paddy fields for rice production are essentially man-made wetland areas and are characterised by high moisture content, oxygen depletion and high organic substrate and nutrient levels.²³ As such, they provide ideal conditions for methanogenic bacteria and result in substantial emissions of methane of approximately 40 Mt per year. Up to 90% of this methane is absorbed by populations of methanotrophic bacteria, which convert the methane to carbon dioxide, but the remaining 10% escapes to the atmosphere. The production of 1 kg of rice corresponds to the emission of 100 g of methane.²⁴ It is worth noting that the accuracy of methane emissions estimates has improved substantially over the past decade, with current figures almost half previous estimates.¹

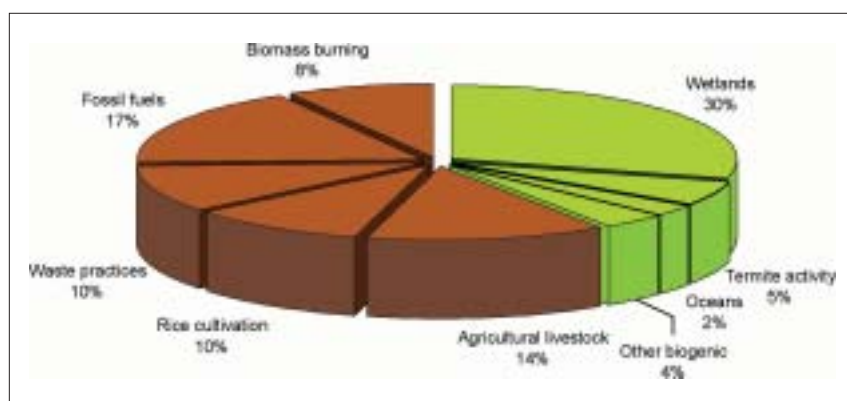


Figure 5: A representative distribution of worldwide anthropogenic and natural sources of methane

Source: Khalil, 2000²¹



Rice paddy soil is fully waterlogged for 4 months each year, creating an artificial wetland

Methane is produced as part of the natural digestive processes of ruminant animals such as cattle, sheep and goats. Food is broken down by bacteria in the rumen, aiding digestion, since stomach enzymes are insufficient to break down plant polymers. However, the action of these bacteria yields methane, carbon dioxide and ammonia as gaseous by-products. With an increasing global population, coupled with higher living standards, livestock numbers are increasing world-wide and contribute some 50-100 Mt per year to global methane emissions.

Landfill sites also provide an anaerobic environment where methanogenic bacteria break down waste organic materials. Somewhere between 40 and 60% of landfill gas is methane, depending on the composition of the waste. The remainder is mainly carbon dioxide with other trace gases. The amount of methane emitted to the atmosphere from a landfill site is strongly dependent on the design and operation of the site. Unchecked, the landfill gas will simply permeate through the waste or along cracks in the compacted waste or bedrock. Modern landfill sites use impermeable liners and a capping layer to control the movement of the gas, which may then be collected. However, even the best caps are only 85% efficient²⁵ with the remaining 15% of methane escaping through the cap.²⁶ This is offset by breakdown of up to 90% of the methane in the capping layer by methanotrophic bacteria (Section 5.1).

The burning of biomass releases around 40 Mt of methane into the atmosphere each year. Biomass burning results mainly in the production

of carbon dioxide, but if fires smoulder and combustion is incomplete, methane and other volatile organic compounds are released. The extent of methane emissions is dependent on the completeness of combustion and the carbon content of the fuel used.²⁷

Methane hydrates

Although currently neither a source nor a sink, methane hydrates are by far the largest store of methane on the planet and account for 53% of all fossil fuels on earth.²⁸ They are a crystalline solid mixture of water and methane (essentially methane trapped in ice) and are found in ocean floor sediments and arctic permafrost. Methane hydrates are stable compounds and are not part of the methane cycle described in this chapter.

The methane in ocean sediment hydrates is trapped by the high pressure deep in the ocean but is released above a depth of 400m as the pressure drops. The energy industry is keen to take advantage of this and mine these deposits.²⁹

Methane contained in arctic tundra, trapped within the frozen solid structure of the hydrate, is a more serious issue. Should temperatures rise, the methane hydrate will melt, releasing methane gas to the atmosphere. There is concern that, if rising global temperatures due to anthropogenic climate change cause the arctic permafrost to melt, massive quantities of methane would be released into the atmosphere, causing a catastrophic run-away greenhouse effect beyond even the upper 5.8°C estimate postulated by the IPCC. Such a process is believed to have occurred in the Palaeocene-Eocene Thermal Maximum,³⁰ some 55 million years ago, when average global temperatures increased by 5°C and which lasted for 150,000 years.

Is it renewable?

The question of whether methane is a renewable resource is central to determining its eligibility for strong financial incentives such as ROCs. Renewable energy technologies are defined as

Flaming ice: methane hydrates are essentially methane trapped in ice



relying on “natural energy flows and sources in the environment, which, since they are continually replenished, will never run out”.³¹

Agricultural emissions, being biogenic are clearly renewable. Methane from landfill is mostly derived from decomposition of plant-based material and once flared is approximately carbon neutral.³² It is also arguable whether waste streams are a ‘natural flow’, but it is assumed that societies will always produce some waste as a consequence of their activities. Landfill gas is therefore defined as a renewable resource. However, if the same waste stream is combusted to generate electricity, this does not count as renewable because fossil-fuel based plastics are incinerated.

Coal mine methane is certainly an energy flow within the environment, but is it a natural flow? As a resource, methane would not be released to the atmosphere were it not for human action, although the same could be argued for landfill gas, which does qualify for ROCs. However, landfill gas is carbon-neutral, whereas the release of coal mine methane must be considered an addition to the present carbon cycle. The DTI does not consider coal mine methane to be a

renewable resource.³³ Methane from the oil and gas industries is also considered non renewable.

Although the issue of what is classified as renewable is not straightforward, especially when considering landfill and coal mine methane, the separation assumed by policy makers is clear. If the methane is generated from biogenic sources, it is renewable. Conversely, if it is derived from fossil fuel sources, it does not count as renewable.

Future outlook

Both natural and anthropogenic sources of methane are likely to change the atmospheric burden over the forthcoming century.¹ There is considerable potential to reduce the anthropogenic sources of methane by improved waste management and changes in agricultural practice. However, these sectors are still prone to upward pressure due to an increasing global population with increasing energy, land and dietary demands. Natural emissions may also increase further as a result of global warming, as higher average global temperatures may stimulate microbial activity.^{2, 20}

2.3 Methane sinks

Methane is removed from the atmosphere (*i.e.* converted to less harmful products) by a range of chemical and biological processes, which occur in different regions of the atmosphere. These include tropospheric oxidation, stratospheric oxidation and uptake by soils.

The troposphere is the lowest 15 km of the atmosphere. As colder air lies on top of warmer air in this section of the atmosphere, the troposphere is well mixed vertically by convection currents. The methane is therefore present at a constant concentration of approximately 1.7 ppm throughout the troposphere. Because atmosphere decreases in density with increasing altitude, over 75% of the atmosphere, and therefore by far the majority of methane, is contained within the troposphere (Figure 6). Oxidation of methane in the troposphere is the

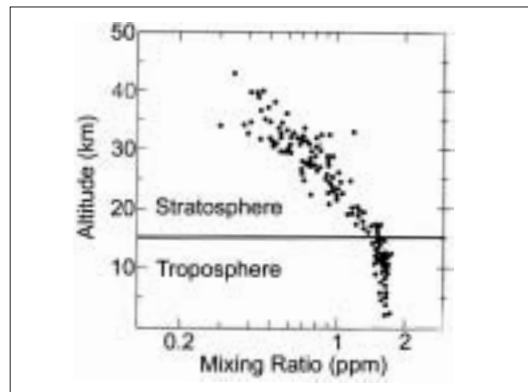


Figure 6: Relative concentration of methane in the atmosphere

Source: Warneck, 1988³⁴

largest methane sink, removing 506 Mt of methane per year from the global methane burden (Table 4). It is therefore changes to the chemistry and composition of the troposphere that will dominate the future environmental impact of methane emissions.

Above the troposphere lies the stratosphere. The stratosphere is less dense than the troposphere and is not mixed vertically by convection, as warmer air lies on top of colder air in this region. Methane enters the stratosphere from below and is consumed by chemical reactions, so the relative concentration of methane decreases with altitude. Stratospheric oxidation of methane consumes 40 Mt per year.

The third process for removal of methane from the atmosphere occurs at the ground-atmosphere interface. Bacteria present in soils can also oxidise methane, thereby removing it from the atmosphere.

Table 4: Sinks of methane

<i>Mechanism</i>	<i>Methane removal (Mt)</i>
Tropospheric oxidation	506
Stratospheric oxidation	40
Soil uptake	30
Total	576
Emissions	598

Tropospheric oxidation

The predominant mechanism for removal of methane from the earth's atmosphere is oxidation within the troposphere by the hydroxyl radical (OH). 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 eventually oxidising methane to carbon dioxide, as would happen if methane were burned.

Reactions between methane and the hydroxyl radical initiates a chain of possible reactions that produce other species, such as carbon monoxide, nitrogen dioxide and hydroperoxide, which can then be removed from the atmosphere. This is a complex process with numerous feedback loops. A more detailed discussion of these reactions is provided in Appendix I.

The overall rate of removal of methane is dependent on the rate of the initial reaction between methane and hydroxyl. This, in turn, is dependent on the concentrations of these species in the atmosphere. This has two important consequences.

- Reaction between methane and hydroxyl removes both species from the atmosphere. As the concentration of hydroxyl reduces, the rate of methane removal will slow down. Increasing atmospheric methane concentrations removes hydroxyl from the atmosphere and so slows its own removal.
- Because the hydroxyl radical - the cleanser of the atmosphere - is capable of reacting with many species, methane is not the only influence on its concentration. Sources of hydroxyl (mainly ozone) are roughly constant, but it may be removed from the atmosphere by reactions with carbon monoxide (CO), nitrogen dioxide (NO₂), hydroperoxide (HO₂) and volatile organic compounds. In particular, the reaction between carbon monoxide and hydroxyl proceeds very rapidly, so carbon monoxide

scavenges hydroxyl from the atmosphere. Increased anthropogenic emissions of carbon monoxide (from transport), coupled with the further carbon monoxide produced from oxidation of methane, can cause significant hydroxyl concentration reductions and so slow the rate of methane removal.

As the rate of methane removal slows, its lifetime in the atmosphere and therefore its GWP will increase. Methane will become a more potent greenhouse gas over time if hydroxyl concentrations continue to decrease. In terms of policy, it is more effective to reduce methane emissions now while hydroxyl concentrations remain relatively high. Delaying action to reduce methane emissions, until a time when hydroxyl concentrations are lower, will result in the emitted methane being more potent.

Furthermore, successful methane emission reductions, preferably accompanied by lower anthropogenic carbon monoxide emissions, could result in an increase in hydroxyl concentrations and a subsequent lowering of the GWP of future methane emissions. This beneficial positive feedback loop is a further reason for encouraging methane emissions reduction in the short term.

Stratospheric oxidation

Some of the methane present in the troposphere passes into the stratosphere. Approximately 40 Mt of methane are oxidised in the stratosphere, representing 7% of all methane removal. The chemistry of methane in the lower stratosphere is identical to that in the troposphere, with hydroxyl radicals oxidising methane in the same manner. Indeed, oxidation of methane to carbon dioxide 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 oxygen atoms. Chlorine atoms are produced by decomposition of CFCs and related compounds by the high intensities of ultraviolet light found in

the upper stratosphere. Oxygen atoms are similarly produced by the decomposition of ozone (O_3) in uv light; it is this reaction in the 'ozone layer' that prevents harmful ultraviolet radiation reaching the earth's surface.

When chlorine or oxygen atoms react with methane, they initiate the same chain reactions that occur in the troposphere, resulting in overall oxidation of methane and removal from the atmosphere.

Uptake by soils

Approximately 30 Mt of methane are removed from the atmosphere annually by uptake in soils. Soils contain populations of methanotrophic bacteria that can oxidise methane, by a process known as 'high affinity oxidation'. These bacteria consume methane that is in low concentrations, close to that of the atmosphere (<12 ppm). The bacteria favour upland soils, in particular forest soils.²⁴ Surprisingly, the bacteria responsible for high affinity oxidation processes remain largely unidentified. It is known, however, that exposure of soils to high ammonium concentrations leads 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 removal of methane.²⁴

2.4 Methane in the atmosphere

The atmospheric concentration of methane is thought to have increased by a factor of 2.5 since pre-industrial times, reaching 1745 ppb in 1998.¹ This rate of increase far exceeds that of carbon dioxide, concentrations of which are only 30% higher than in pre-industrial times. In fact, information is sufficient for the IPCC to assert that the current methane concentration has not been exceeded in the last 420,000 years.¹

Ecosystems may not be able to adapt to a rapid rate of climate change



How much heat is being trapped?

The amount of 'extra' energy being held within the earth's atmosphere because of the rise in atmospheric GHG concentrations is termed radiative forcing, measured in units of watts per metre square (W/m^2). Radiative forcing is the change in radiation balance due to a change in greenhouse gas concentrations over a quoted timeframe. The total radiative forcing of the well-mixed greenhouse gases since pre-industrial times (1750) is 2.43 W/m^2 . Of this, the radiative

forcing of methane is 0.48 W/m^2 . It is important to note that this is not the radiation absorbed by the 1745 ppb methane in the atmosphere. Rather it is the radiative forcing of the extra 1045 ppb methane present in the atmosphere since 1750. Essentially the radiative forcing is the difference in rate of heat capture now versus then.

Table 5: Radiative forcing of selected greenhouse gases

	CO_2	CH_4	N_2O
Pre-industrial concentration (ca. 1750) ppb	280,000	700	270
Concentration in 1998 (ppb)	365,000	1745	314
Relative concentration 1998/1750	1.30	2.49	1.16
Radiative forcing (W/m^2)	1.46	0.48	0.15
Atmospheric lifetime (years)	5-200	12	114

Source: IPCC, 2001¹

From Table 5, it can be seen that carbon dioxide is the most important greenhouse gas, with a radiative forcing of 1.46 W/m^2 . Methane is the second most important anthropogenic greenhouse gas, contributing 20% to the total radiative forcing, proportionally far greater than expected according to atmospheric concentrations of the gases. The explanation lies in the considerable potency of methane as a greenhouse gas.

Global Warming Potential

The different greenhouse gases vary in both potency and their lifetime within the atmosphere. On emission, different greenhouse gases have different abilities to absorb radiation. However, the radiative forcing of the emitted gas decays exponentially as the gas is removed from the atmosphere over time and the concentration

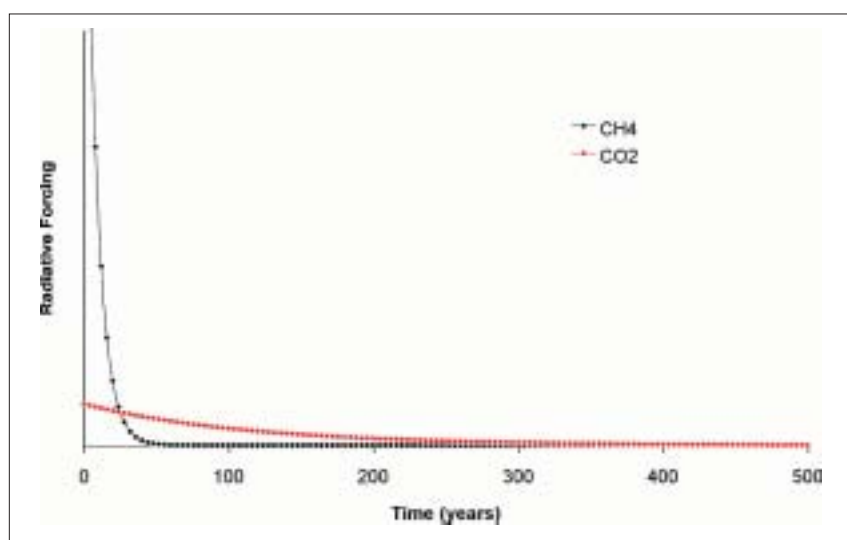


Figure 7: Radiative forcing of methane and carbon dioxide

decreases (Figure 7). The rate of this removal is dependent on the atmospheric lifetime of the species involved. It is therefore difficult to determine an absolute measure of the relative effects of one tonne of each gas, because these will vary over time. In fact, it is impossible to combine the two influences of potency and lifetime into a single definitive figure that reflects the properties of a greenhouse gas. However, it is useful to have one single parameter that reflects the influence of different gases, especially under multi-gas abatement schemes such as the Kyoto Protocol and other emissions trading schemes.

Table 6: Global Warming Potentials for the greenhouse gas ‘basket’

Gas	Lifetime (years)	Global Warming Potential (time horizon in years)		
		20 years	100 years	500 years
CO ₂	5-200	1	1	1
CH ₄	12	62	23	7
N ₂ O	114	275	296	156
HFCs	0.3-260	40-9,400	12-12,000	4-10,000
PFCs	2,600-50,000	3,900-8,000	5,700-11,900	8,900-18,000
SF ₆	3,200	15,100	22,200	32,400

Source: adapted from Table 3, IPCC 2001¹

The Global Warming Potential (GWP) is the parameter that has been adopted.

The GWP of a greenhouse gas is defined as “the [cumulative] radiative forcing from the instantaneous release of 1 kg of a trace substance relative to that of 1 kg of a reference gas”.¹ The reference gas is almost always carbon dioxide and so its GWP is always unity (Table 6). In visual terms, this is the relative area under the curves in Figure 7, up to a certain time limit. Short-lived gases such as methane have higher GWPs under short time-horizons. Conversely, long-lived species such as SF₆ have higher GWPs under long time-horizons. Table 6 shows the Global Warming Potential of the basket of six greenhouse gases over three different timeframes.

The effect of different time horizons poses interesting questions with regards to policy. Which value of GWP should be used to assess the relative importance of methane emissions versus carbon dioxide? The Kyoto Protocol and other key policies use the 100-year time horizon, although these are currently based on the old GWP for methane of 21 given in the IPCC’s Second Assessment Report. This will be updated to 23 for the second commitment period (2013-17). The IPCC most frequently quotes the 100-year GWPs, although has made no policy recommendations as to which GWP timescale to use.

Calculating CO₂ equivalent emissions

It proves useful to measure the potency of greenhouse gas emissions in one set of units: tonnes CO₂ equivalents (t CO₂e). To calculate the impact of methane emissions, the mass emitted is multiplied by the 100-year GWP. One tonne of methane is deemed equivalent to 23 t CO₂e.

It is also important to note that GWP is defined in terms of mass of emitted gas, not volume. Care must be taken if GHG emissions are measured as volumes – one litre of carbon dioxide weighs 2.75 times as much as one litre of methane. So one litre of methane is 8.4 times (23/2.75) as potent as one litre of carbon dioxide.

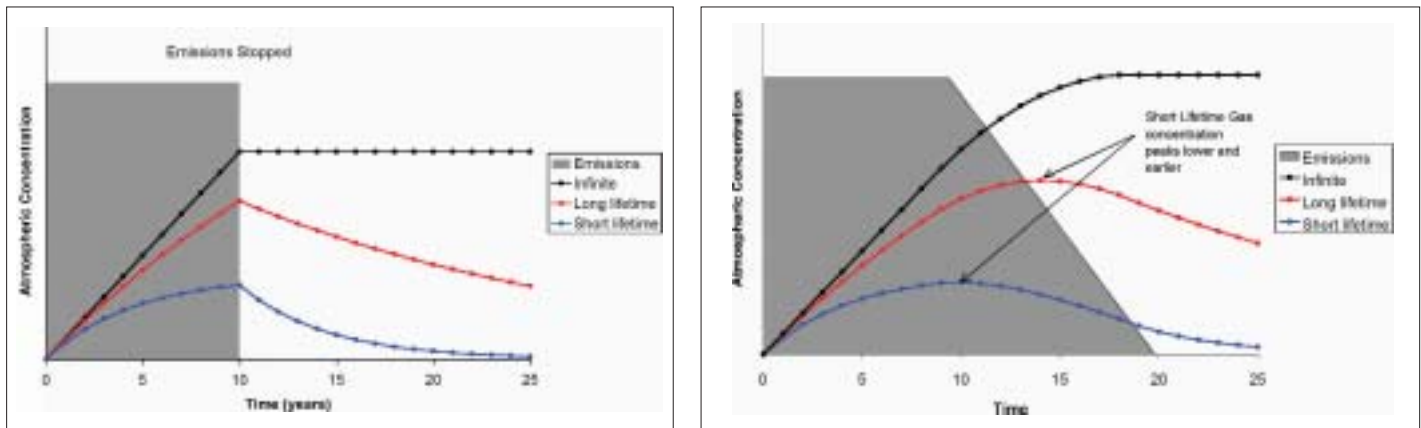


Figure 8: Effect of emissions cessation (a) and gradual reduction (b) on atmospheric concentration

The influence of lifetime

The Global Atmospheric Lifetime of methane in the atmosphere is defined as the atmospheric burden (concentration) divided by the sink strength (annual removal).

$$\text{Global Atmospheric Lifetime of CH}_4 = \frac{\text{Atmospheric burden}}{\text{Sink strength}} = \frac{4850 \text{ Mt}}{576 \text{ Mt}} = 8.4 \text{ years}$$

However, the chemistry of methane in the atmosphere contains several feedback loops affecting the concentration of other atmospheric species such as O_3 and OH , which slows the removal of GHGs (including methane itself) from the atmosphere. This feedback effect is included in the Perturbation Lifetime, which is longer than the Global Atmospheric Lifetime and is equal to 12 years. The Perturbation Lifetime is the standard figure used.

For constant emissions, species with a short lifetime do not reach such high atmospheric concentrations because they can be removed more rapidly from the atmosphere. If emissions

are stopped completely, as shown in Figure 8a, the atmospheric concentration of a short lifetime gas will drop away much more rapidly than a gas with a long lifetime.

A sudden stop in emissions of a particular gas is an unlikely scenario, so Figure 8b looks at the effect of gradually reducing emissions over a period of time. It can be seen that the concentration of the short lifetime gas reaches its peak earlier and also drops away more rapidly after this point. This means that policies targeting short-lived gases, such as methane, will rapidly lead to tangible atmospheric concentration reductions. Gases with a longer lifetime reach higher atmospheric concentrations and experience a longer lag between emissions reduction and atmospheric concentration reductions. Reducing emissions of short-lifetime potent gases such as methane is therefore a valuable means of rapidly slowing global temperature rise.

Methane emissions trading



One of the key issues in this report is whether methane trading is a viable option for the UK. Market based trading schemes are currently a popular option for dealing with a range of environmental issues. A consequence of the diverse and diffuse nature of methane sources is that policies with the potential to address the mitigation of methane emissions are similarly varied and tend to be focused within the individual sectors (e.g. waste, agriculture, coal mines). Methane emissions trading offers the possibility of a consolidated approach that could apply across all sectors.

This chapter explains the concept of emissions trading and looks at both the UK and EU Emissions Trading Schemes, before outlining the options for trading methane. This sets the context for the remaining chapters in which the various sources of methane are discussed in detail and the possibility of methane trading for each sector is explored, amongst other policies for the mitigation of methane emissions.

3.1 Emissions trading concept

Emissions trading is a mechanism for delivering emissions reductions at minimum economic cost. It is a move away from the traditional 'command-and-control' regulatory approach to a market-based mechanism, directly involving those responsible for the emissions and allowing the polluters to decide their own emissions abatement pathway. Trading is therefore seen as a highly attractive option by both corporations and government and has become a central tenet of international policy to reduce greenhouse gas emissions, such as the Kyoto Protocol.

The UK has already implemented the first industry-wide trading system incorporating carbon dioxide, methane and other greenhouse gases. The EU Emissions Trading Scheme starts in 2005, although initially this will only cover carbon dioxide. Opportunities to include methane in the EU ETS are under review, but it will be 2008 at the earliest before methane is included.

Historically, trading was first proposed as an environmental policy instrument in the 1960s.^{35,36} Trading has become an increasingly popular measure over the last two decades, especially as part of pollution reduction regimes in the USA. In particular, trading is credited with the significant reduction in emissions of sulphur dioxide (a major source of acid rain), although it has been argued that these reductions would have occurred anyway.³⁷

As a policy tool, trading is well suited for GHG emissions control because the costs of reducing emissions vary widely between individual greenhouse gases, sectors and countries, providing opportunities and large potential gains from trade.³⁸⁻⁴⁰ The international carbon trading market is expanding rapidly and more than doubled in size in 2003 to 70 Mt CO₂e.⁴¹

How does trading work?

A traditional command-and-control approach imposes absolute performance or technological standards on companies, but takes no account of the individual economic burden placed on those companies.⁴² Such an approach is illustrated in Figure 9a, where the two plants face different abatement costs for achieving the same reductions in emissions. In Figure 9b, under emissions trading, the market determines the price of the commodity and the benefit to the company is determined by the difference between the abatement cost and market price. For instance, plant 1 gains £15 since it can reduce emissions by one tonne at a cost of £5 and then sell this credit on the market for £20. Instead of plant 2 actually undertaking emissions reductions and paying £30 per tonne, it can purchase a credit on the market for £20, thereby making a saving of £10 compared to the regulated approach. Hence, the overall cost of reducing two tonnes under trading is just £10, instead of £35 under the regulated scenario shown in Figure 9a.

Trading therefore has the advantage of enabling the most cost-effective implementation of the overall target, with cost benefits to all

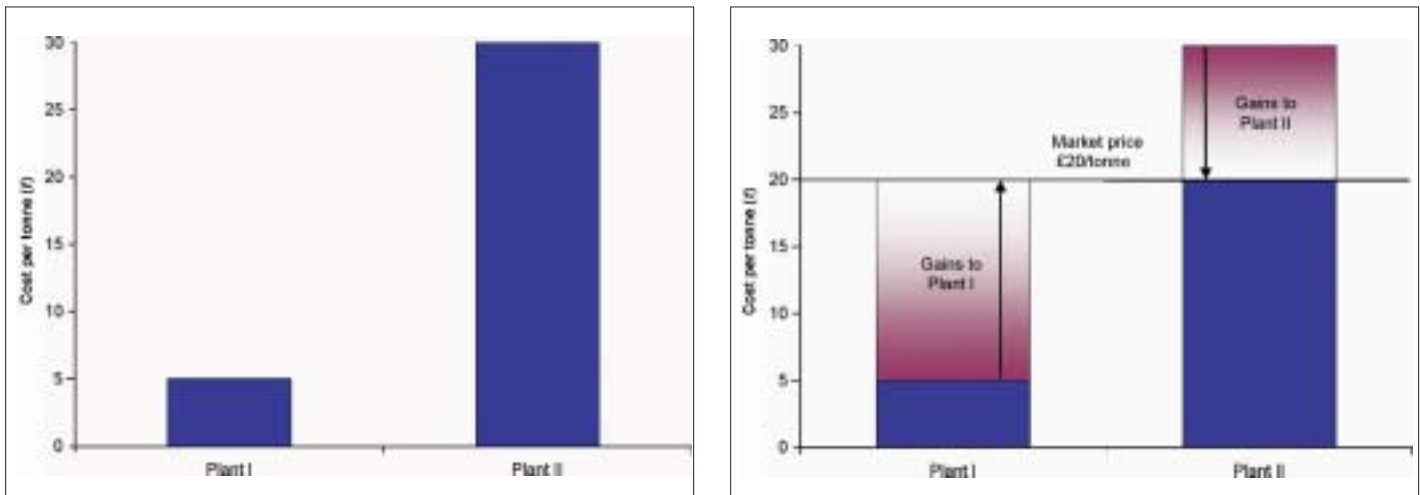


Figure 9: Comparison of (a) regulated approach & (b) market trading approach

companies irrespective of their individual abatement costs. Furthermore, trading provides incentives to invest in environmentally sound technologies. Emissions trading is thus seen as the “least bad of all options”⁴³ in terms of policy.

The carbon trading market is merely a mechanism for ensuring that baseline targets are met and its success in achieving significant greenhouse gas emissions reductions depends simply on where the baseline is set. Emissions trading combines buying and selling of emissions with the *right to emit* GHGs, identified through company or country specific allowances (also referred to as quotas, permits or caps). The total allowance of a regulated pollutant is determined centrally by government or international bodies. This baseline is reduced over time to achieve the desired emissions reduction in the required timeframe.

Allowances are distributed to entities, allowing market forces to control their price, and can be assigned in two ways: either through an auction, where allowances are sold on a market basis, or by ‘grandfathering’, where allowances are allocated on a discretionary basis, typically based on the historical emissions of an entity. Ideally, the system should reward companies that have already taken action to reduce emissions and penalise those that have not; grandfathering

enables such flexibility. Within a classic ‘cap and trade’ scheme, participants take on targets requiring them to reduce their emissions to a capped level, which may be more or less stringent than the overall baseline reductions.

Trading emissions is no different from trading other commodities. Once allocated or created, emissions allowances act as fully interchangeable commodities and they can be bought, sold and traded, or in some circumstances banked for future use. Account holders in a central registry can buy and sell allowances and trade either between themselves or with third party brokers. Entities with low abatement costs (costs of reducing emissions) or those that reduce their emissions by more than their allocated amount can sell their surplus (‘carbon credits’) to others who are not able to reach their target easily.⁴² Conversely, companies that exceed their limits can choose to purchase allowances on the open market to match their emissions or invest in abatement technology, generally whichever is cheaper. The market price of allowances will rise if the overall baseline is not being achieved, since demand will increase, and fall if overachieved. Allowances can even be retired without counterbalancing an actual emission thereby making the adopted baseline stricter and creating an additional environmental benefit.



The UK ETS covers emissions from both the generation and use of energy

When trading methane that has been combusted, either by flaring or to recover energy, the negative impact of emitting the combustion product carbon dioxide must also be accounted for. Burning one tonne of methane (equivalent to 21 tonnes of carbon dioxide) produces 2.75 tonnes of carbon dioxide. One tonne of combusted methane is therefore equivalent to 18.25 tCO₂e (21 - 2.75).

3.2 Emissions trading schemes

International Emissions Trading is the major mechanism of the Kyoto Protocol but, with the delay in ratification, other emissions trading schemes have been developed, most notably the UK and EU Emissions Trading Schemes (UK ETS and EU ETS).

UK Emissions Trading Scheme

The UK ETS was launched in April 2002 as a voluntary scheme to run until December 2006. The aims of the UK ETS are two-fold: to deliver cost-effective greenhouse gas emissions reductions and to provide UK industry with practical experience of emissions trading ahead of a European or international system. In this manner, UK businesses should be well placed to take a leading and influential role in both development and use of these wider schemes. The UK ETS was expected to deliver total savings of 2-4 Mt CO₂e by 2006 through encouraging fuel switching in power generation, principally from coal to gas.

Both direct and indirect emissions are covered in the UK scheme, meaning that emissions associated with both the generation and use of

energy are included. The scheme covers all industrial sectors apart from power generators. Landfill sites, households and the transport sector are all exempt.

The UK ETS is also unique in that it is a multi-gas trading system. Methane has been actively traded as part of this scheme by participants such as UK Coal, Shell and BP.⁴⁴ Allowances are traded in the 'currency' of carbon dioxide equivalents; the exchange rate for methane is simply the 100 year GWP of 21.

Participation in the UK ETS takes three forms: direct participation, as a climate change agreement (CCA) participant and as a trading participant. All participants are committed to the scheme for its full duration.

Direct participants operate on a 'cap and trade' basis and are required to make an absolute reduction in emissions against a 1998-2000 baseline over the period 2002-06. If targets are not achieved, penalties, and ultimately fines, are incurred. To encourage participation in the scheme, participants received incentive payments from the Government, set through a competitive bidding process. The UK Government committed a total of £215m incentive money (after tax), payable over five years (2002-6).⁴⁵

A total of 34 companies were successful in the auction of the five-year allowances, which took place in February 2002. These include Ineos Fluor, Dupont, Shell, UK Coal and BP. Collectively these companies have committed to reduce emissions by around 4 MtCO₂e/yr by December 2006. At the end of each year, organisations have a three month reconciliation period to compile their verified emissions report. By the end of this period they are required to demonstrate to the Government that they have sufficient allowances to cover all of their emissions. The first year results show 31 out of 32 direct participants met their emissions reductions targets.⁴⁵ All participants trading methane are acting as direct participants.

Climate change agreement participants are those companies already covered by the Climate

Change Levy (CCL). These participants use the emission or energy targets previously set through the CCL agreement, which, if met, entitle them to an 80% discount on the levy. This form of trading, sometimes referred to as 'baseline and credit', is used to either help meet the target by purchasing allowances, or by selling any over-achievement. If the target has been met and the over-achievement verified, allowances are given at the end of each compliance period. Targets for CCA participants are defined in terms of absolute emissions reductions (tonnes CO₂e) or relative targets according to levels of output (tonnes CO₂e per tonne product).

CCA participation covers 866 firms⁴⁶ which are expected to deliver additional emission reductions of over twice that of direct entry ETS participants.⁴⁷

Trading participants are companies, brokers or individuals not subject to reduction targets who opened trading accounts with the Emissions Trading Registry, which they then use to buy or sell allowances. In the first year of trading there were 35 active trading participants.⁴⁸

A fourth option that has been considered in the UK, but is not part of the current scheme, is participation through projects: the generation of credits from new emission reduction projects in the UK. Under this route, projects are not assigned a baseline and therefore the emissions reductions have to be quantified. The savings must also be additional (*i.e.* the reductions would not have occurred without the project). The UK Government decided not to use this option because of the risks associated with it in light of the EU's proposal for linking Joint Implementation (JI) and Clean Development Mechanism (CDM) projects into the EU ETS.⁴⁸

EU Emissions Trading Scheme

The EU ETS starts on 1 January 2005 and will be the first multinational scheme in the world with emissions trading between Member States of the enlarged European Union.

The European scheme is mandatory and covers

only direct emissions. It is divided into two phases: an initial phase (2005-2007) and a main phase (2008-2012) concurrent with the first commitment period under the Kyoto Protocol. Six sectors are covered: energy activities (all plants over 20 MW), oil refining, cement production, iron and steel manufacture, glass and ceramics, and paper and pulp production. The first phase of the scheme will only cover carbon dioxide emissions, but this will be reviewed by the Commission in 2006 and may be extended to other greenhouse gases, including methane. Gases not covered under the Kyoto Protocol may still be eligible for trading. Additional sectors will also be considered. The scheme may also be expanded to permit European companies to carry out emissions curbing projects around the world, as proposed by the European Commission in the 'Linking Directive'. This would convert credits earned into emissions allowances in the same manner that JI and CDM projects would work under the Kyoto protocol.

Member states were required to develop a national allocation plan for emission permits to companies by March 2004. This grandfathering process set targets for the relevant sectors and delineated methods for division of allowances (each worth 1 tonne CO₂) between participants of the respective Member States. The Directive allows up to 5% of allowances to be auctioned in 2005 and 10% after 2008. So far this process has resulted in a great deal of controversy with companies disputing their allocations.

All installations must meet their targets by reducing emissions or by buying allowances. Installations without sufficient allowances to cover their emissions will pay a direct financial penalty (40 € per tonne CO₂ from 2005-7, 100 € per tonne thereafter) and have to make up the deficit in subsequent commitment periods. For installations that have a surplus of allowances, Member States can allow banking.

More than 12,000 installations – representing approximately 46% of the EU's total carbon dioxide emissions – will participate in the scheme.

Market analysts predict that trading could be worth more than €7-8 billion a year by 2007, creating a brand new financial market.⁴⁹ Although the scheme does not start until 2005, the first deals have been brokered already with up to 250,000 credits traded in just one day.⁵⁰

Interaction of the UK and EU ETS

The UK and EU Emissions Trading Schemes differ on a number of issues (Table 7), which essentially make the two systems incompatible. One of the key differences lies in the trading arrangements: the EU scheme considers direct emissions only

Table 7: Comparison between the UK and EU Emissions Trading Schemes

	<i>UK ETS</i>	<i>EU ETS</i>
Type of scheme	• Voluntary	• Mandatory
Period	• 1st period 2002-2006 • No guarantee of 2nd period, but review in 2005	• Phase 1 2005-2007 • Phase 2: 2008-2012
GHGs	• All six GHGs	• Only CO ₂ in Phase 1 • Other gases may be included in Phase 2, provided adequate monitoring and reporting systems are available and provided there is no damage to environmental integrity or distortion to competition
Sectors	• Indirect and direct emissions (end-user) • All industrial sectors except power generators • Transport, landfill, households exempt	• Direct emissions (source) only • Subset of IPPC sectors, excluding chemicals, food and drink and waste incineration • Energy activities (all plants over 20 MW), oil refining, cement production, iron and steel manufacture, glass and ceramics, and paper and pulp production
Type of targets	• Direct entrants (absolute targets) • CCA participants (absolute or relative targets)	• Absolute targets for all participants
Market size	• 34 direct entrants (~ 1 MtC-reductions over 5 years) • ~6000 CCA businesses (~ 2.5 MtC/year)	• More than 12000 installations (Phase 1) • 46% of EU carbon dioxide emissions
Allocation method	• Financial incentive (auction) for direct entrants • Negotiated energy saving targets through CCAs	• Member states decide allocation method. They have the option to auction up to 5% in Phase 1 and 10% of allowances in Phase 2 • Commission retains the right of veto over national allocation plans
Compliance	• Loss and repayment of financial incentive for direct participants • Statutory penalties to be introduced • CCA participants have separate compliance procedures	• Penalty of 40 €/tonne. • Increased to 100 €/tonne after 2008

Methane will not be included in the EU ETS until 2008 at the earliest



whereas the UK ETS incorporates emissions from end-users as well. Now that the EU scheme has been approved to start in 2005, it is highly unlikely that the UK ETS will continue beyond its current phase (2002-2006). The UK Government has confirmed that there will be no transfer of credits between the two schemes.

Cessation of the UK ETS in 2006 will have consequences on the trading of methane since methane will not be included in the EU ETS until 2008 at the earliest.

Methane trading

Although methane is already being traded successfully in the UK ETS, this is currently limited to emissions from active coal mines and offshore gas, thereby excluding a large proportion of other anthropogenic methane emissions. With the likely closure of the UK ETS in 2006, even this restricted level of trading will cease. There is no guarantee that methane will be incorporated into the EU ETS in 2008 and even if it is, there will still be a two year gap until methane trading is possible again. This delay will act as a deterrent to investment in methane capturing technologies if trading is the main incentive.

A separate methane market is not a viable option in the UK because the market would be too small to be liquid. For methane to be traded it must be incorporated into a multi-gas trading scheme.

If methane is included in the EU ETS from 2008, there are two possible routes through which methane could be introduced: through new installations or via the project entry route.

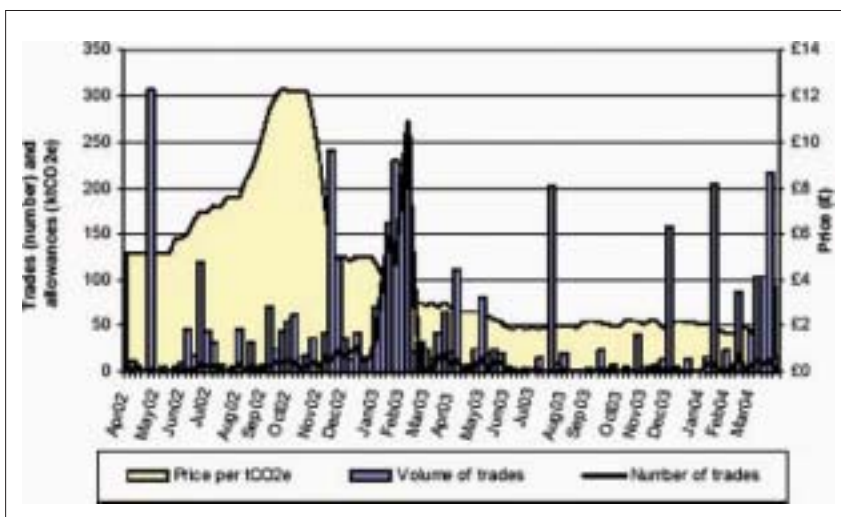
New installations. As part of the EU ETS review in 2006, new sectors beyond those specified in the first phase will be considered for inclusion in the scheme. This could open up methane trading from sectors such as the gas industry.

Project entry route. New projects have the potential to encourage emissions reductions, but only if the emissions reduction obtained is additional (*i.e.* they would not have occurred in the absence of the project).⁵¹ Through the 'Linking Directive', JI and CDM projects would permit entities in industrialised countries to develop greenhouse gas reducing projects.

However, because the EU ETS is focused on large emitters of carbon dioxide, small-scale emitters in the methane sector, such as farmers, are unlikely to be able to participate without aggregation.

Figure 10: UK ETS carbon prices, 2002-4

Source: DEFRA, 2004⁵⁵



3.3 Review of the UK ETS

The UK ETS has provided companies with experience of trading and established a trading support industry. However, there are some aspects of the scheme that were not wholly successful, providing valuable lessons in developing an effective emissions trading scheme.

In the first year of the UK ETS, trading went well with over 32 million allowances allocated to companies. Selling activity was initially dominated by a few direct participants.⁴⁷ This forced the price of carbon up to a peak of £12.40/t CO₂e in October 2002 (Figure 10). As more CCA companies had their emissions verified towards the end of the year, they then had

emissions to offer to the market causing the balance of selling activity to shift and the price to slump to £5/t CO₂e.⁵² Such problems are partly due to lack of liquidity in the UK market: the market is highly skewed as a result of the structure of the scheme, with very few players and the sellers generally outweighing the buyers.^{53, 54} Also, activity is dictated by CCA participants, who have provided much of the buying activity so far,⁵⁴ as most trading occurs when they need to demonstrate compliance once every two years. Shorter compliance periods would have ensured a more constant level of trading. Shorter compliance periods would have ensured a more consistent level of trading.

However, the direct participants are larger companies with lower abatement costs, and have sold to the CCA participants, who in general will have higher abatement costs due to economies of scale. In this sense, the scheme has been successful in achieving emissions reductions at lowest cost.⁵⁵

To date, approximately 2,000,000 allowances (1 allowance equals 1 tonne CO₂e) have been traded in the market, of which 580,000 allowances were bought for CCA compliance. Some sophisticated direct participants (e.g. oil companies) have been active in both in buying and selling, trading speculatively rather than as direct participants. Activity in the UK ETS has now dropped since CCA companies do not have to prove compliance until February 2005 and so there is no immediate incentive to purchase allowances in the market. There is still a limited amount of trading, with CCA companies buying at the current low price to hedge against future risks of price increases and meeting CCA targets. Allowances purchased now can be banked and used towards later targets.

The market integrity and environmental effectiveness of the scheme was badly damaged due to an imbalance in allocation of allowances amongst the direct participants.^{56, 57} Although the achieved emissions reduction was over six times greater than the direct participants'

collective target, the majority of savings came from just two companies, both of whose emissions were expected to fall anyway through regulatory requirements.⁵⁶ In other words, DEFRA awarded a huge 'hot air' surplus and compromised the integrity of the scheme, a fact which they have acknowledged.⁵⁵ The price of carbon had slid down to £1.75/t CO₂e by August 2003 as a result of oversupply from the direct participants.⁵⁸

Hence, although the UK ETS might have stimulated significant market activity, its effectiveness in contributing to greenhouse gas emissions reduction targets is questionable.⁴⁷ There is debate as to whether the scheme has delivered significant quantities of absolute emission reductions with participating firms reducing emissions further than would have occurred in the absence of the scheme.

3.4 Conclusions

Reflecting on the experience of the UK ETS, it is possible to identify some critical factors essential for effective emissions trading markets:

- *Commodity to trade.* To state the obvious, for trading to occur, there has to be a product or commodity to trade. This must be of sufficient volume and from enough individual sources to encourage liquidity. In practical terms, it must be possible to quantify the amount of gas recovered, which can be done most easily through capture.
- *A liquid market.* Emissions trading schemes must have sufficient supply and demand, supported by financial derivatives, if they are to function effectively.⁵⁹ In traditional commodity trading, markets are driven by supply and demand and the incentive to make profits, but, in the case of emissions trading, the system is driven by legislation which operates in a highly uncertain environment. Trading markets work more efficiently as their size increases. The more liquid the market, the more quickly a market price is established, offering greater certainty to all market participants.

- *Suitable mix of players.* Markets do not function efficiently if there is disparity in the size of players. Under the UK ETS, two large companies dominated the selling activity, set against the thousands of small CCA participants as buyers. For brokers, it is more cost efficient to trade large volumes of commodities than small volumes with many players, as the transaction cost for the latter will be high.⁵⁴
- *Additionality.* It is a primary requirement of any trading scheme that credits for reducing emissions must be additional to those required to fulfil other regulatory obligations such as the Renewables Obligation. This will avoid the double counting of emissions reductions ('hot air') that occurred in the UK ETS.⁵⁶ This also means that any new legislation will affect the viability of trading and, conversely, participation in a trading scheme makes legislating difficult. Governments are therefore faced with a choice as to whether to legislate or allow trading. This is a particularly difficult decision with regards to methane in the UK due to the two year gap between the UK ETS finishing and methane being introduced into the EU scheme.
- *Monitoring, reporting and verification.* Standards must be in place for setting baselines and reporting and verifying emissions for an entity. High standards of monitoring, reporting, verification and compliance are crucial to guarantee the environmental integrity and financial credibility of any emissions trading scheme.^{60, 61} A reliable baseline against which savings can be measured is crucial. This gives certainty to what is being exchanged, the obligations to be met and sanctions to be imposed (in the case of non-compliance). Accurate verification of emissions also helps prevent incorporation of 'hot air' into the trading system, which can lead to a fall in market price.
- *Conflicting policies.* It is important to identify whether there are existing policies which may conflict with the trading scheme and thereby affect viability of the market. For instance, if the price of ROCs is higher than the market price for carbon, companies may choose not to trade and opt for ROCs instead.

Potential for methane trading

Methane trading has the potential to act as a strong incentive towards achieving significant reductions in methane emissions. However, not all methane produced in the UK will be eligible for trading: the diversity of methane sources means there is similar diversity in the feasibility of trading amongst different methane generating sectors. The criteria identified here will be used in the following chapters to assess the potential for methane trading in each of these sectors.

Methane in the UK



The UK is party to the UN Framework Convention on Climate Change (UNFCCC), which came into force in 1994 and requires accurate reporting of emissions. The UK is committed to reducing greenhouse gas emissions to 12.5% below 1990 levels by 2010. As a UNFCCC signatory, the UK must monitor progress towards achieving these targets by compiling a UK inventory and publishing an annual inventory report which includes a break down of emissions by anthropogenic source. The National Atmospheric Emissions Inventory⁶² provides detailed methane emissions data from 1990, enabling major trends and the relative contribution of different sources to be identified.

Reports have been published annually since 1995, although it is important to note that figures in these reports have been revised over time as monitoring and modelling procedures have been refined and become more accurate. Emissions data for 1990 have therefore altered over the course of the inventory development and baseline levels for Kyoto Protocol commitments have also changed.

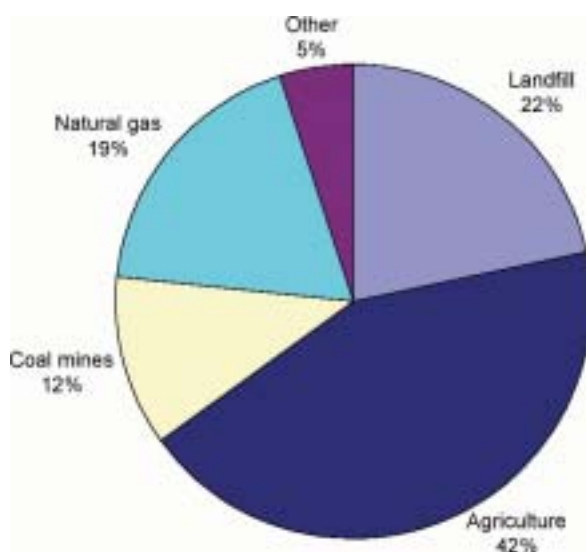


Figure 11: UK sources of methane, 2002

Source: Baggott, 2004⁶³

4.1 UK methane sources

In 2002, 2.10 Mt of methane was emitted from anthropogenic sources in the UK.⁶³ This represents 6.9% of all UK GHG emissions. On a global scale, the UK is responsible for approximately 0.7% of all anthropogenic emissions of methane, from approximately 1% of the world's population.

The major sources of methane in the UK are agriculture, landfill waste, natural gas leakage and coal mining. Together these sources account for 95% of total anthropogenic emissions (Figure 11).

Agriculture is the dominant anthropogenic source of methane, responsible for 0.91 Mt(CH₄) of emissions in 2002. Of the total agricultural emissions, around 90% is derived from the digestive processes (enteric fermentation) in animals, whilst the remainder is from animal wastes. The second largest anthropogenic source of methane in the UK is the anaerobic decomposition of biodegradable waste in landfill, accounting for 0.46 Mt(CH₄) of emissions. Leakage from natural gas distribution and emissions from active coal mines account for a further 0.39 and 0.24 Mt(CH₄) respectively. However, it is important to note that the methane seepage is from active coal mines *only*; emissions from old unused mines are not included in the inventory. Inclusion of abandoned coal mines would add up to a further 0.3 Mt to UK methane emissions.⁶⁴ Other measurable sources of methane include manufacturing, transport and waste water handling, accounting for 0.10 Mt(CH₄) per year.

4.2 Historical trends

Historically, coal mines were the dominant source of methane in the UK. However, after the miners' strike in 1984, the coal mining industry declined and emissions from active mines fell as the number of working pits decreased (Figure 12). By 1990 landfill sites had become the primary source

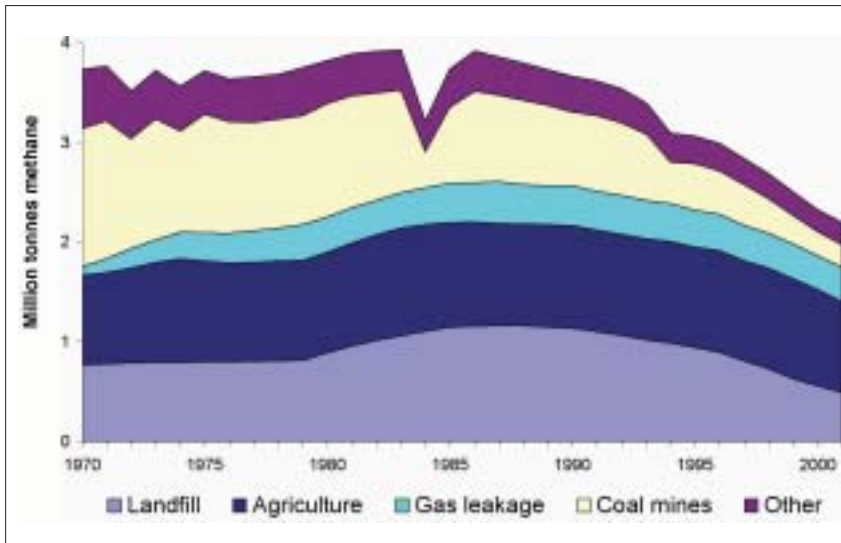


Figure 12: Long term trends in methane emissions, UK

Source: DEFRA, 2003⁶⁵

of methane. However, emissions from landfill sites have decreased throughout the 1990s, mainly due to improvements in methane capturing technologies and improved landfill caps (Chapter 5). Since 1993, the agricultural sector has been the dominant source of methane in the UK. Emissions reductions within this sector have been small, so the relative importance of agriculture to total UK methane emissions has steadily increased.

Since 1990, the baseline year for the Kyoto Protocol, there has been a reduction in methane emissions from all methane-emitting sectors. Most notable is the drop in emissions from coal mines, which decreased by approximately 70% between 1990 and 2002 (Table 8). This is due to the decline in the number of operating mines in the UK. Emission reductions from active coal mines are deemed responsible for 37% of the total methane reductions and 12% of all greenhouse gas emissions reductions since 1990, according to the UK inventory. However, because emissions from abandoned mines are not included in the inventory, this is unlikely to be a true

representation of 'real' methane emissions from this source.

Significant reductions in methane emissions arising from landfill sites have also been achieved over the last decade. Between 1990 and 2002, emissions fell by 61%, accounting for 45% of the overall reduction in methane over this period. Since 1990, methane emissions in the oil and gas industry have declined by 24%. The smallest methane reduction was within the agricultural sector, where emissions fell by only 13% despite the well-publicised livestock farming crises of BSE and Foot and Mouth, which affected livestock numbers.

The significant reductions made by some sectors but not others pose questions to technologists and policy makers alike. Have landfill gas abatement technologies reached their potential, making further reductions expensive? Are the small reductions observed from the agricultural sector because it is inherently difficult to reduce emissions without reducing animal numbers and damaging the industry? And what policies should be implemented to maximise further emissions reductions at minimal economic and social cost? These issues are discussed on a sector-by-sector basis in Chapters 5 to 8.

4.3 Breakdown by region

In 1999, legislation was introduced to devolve power to the regions of the UK and led to the formation of the Scottish Parliament, National Assembly of Wales and the Northern Ireland Assembly. It is the responsibility of these devolved administrations to ensure that Kyoto targets are met in their areas. The UK Government is responsible for ensuring such targets are met in England and also retains some over-arching powers such as taxation measures that can be applied to the entire UK.

It is therefore useful to examine the regional spread of greenhouse gas production in the UK to provide data relevant to England and each of the devolved administrations. Disaggregated data

Table 8: UK methane emissions from 1990-2002 (Mt CH₄)

	1990	1995	2000	2002	% decrease 1990-2002
Landfill	1.17	0.97	0.59	0.46	61%
Agriculture	1.03	1.01	0.97	0.91	13%
Natural gas	0.51	0.48	0.40	0.39	24%
Coal mines	0.82	0.50	0.27	0.25	70%
Other	0.13	0.10	0.10	0.10	22%
Total emissions	3.66	3.06	2.32	2.11	43%

Source: Baggott, 2004⁶³

exist for the four home nations for 1990, 1995 and 1998 to 2000⁶⁶ (Table 9).

Table 9: Regional breakdown of methane and total GHG generation, UK, 2000

	Methane (%)	All greenhouse gases (%)
England	71.5	73.6
Scotland	11.6	10.9
Wales	8.6	8.0
Northern Ireland	5.9	3.2
Unallocated	2.4	4.2

Source: Salway, 2003⁶⁶

The regional production of methane follows the same trends as total GHG emissions, as might be expected from simple farm area and population arguments. A regional breakdown by source presents a different picture, with agriculture being more predominant, and landfill less important, in the more sparsely populated nations with their mainly rural economy. Oil and gas emissions are concentrated in the more industrial nations, and coal emissions only from those nations with active coal mines (Figure 13).

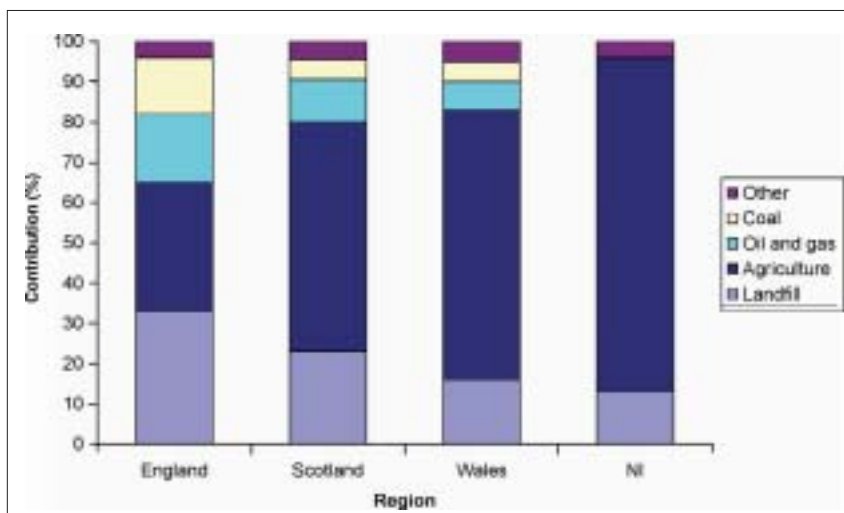


Figure 13: Methane emissions by source and region, 2000

Source: Salway, 2003⁶⁶

4.4 Data uncertainties

Whilst the general trends in methane emissions data are widely accepted, there is less confidence surrounding the exact figures presented. The IPCC reports this to be a generic problem, hindering efforts to provide quantitative projections of future methane emissions.¹

Since the UK's first submission to the UNFCCC in 1997, the emissions inventory has undergone substantial revision (including the 1990 baseline figure). A number of studies were commissioned with the aim of quantifying methane emissions more accurately. In particular, estimates for landfill emissions have been reduced significantly and figures for gas pipeline leakage have been increased. Despite these efforts, the uncertainty level for methane emissions data is $\pm 14\%$ overall,⁶³ and higher for individual sources. Variations in emissions estimates from landfill are $\pm 48\%$ and for gas pipe leakage between 17 and 75%, depending on the type of gas main and service. In the agricultural sector, animal numbers are accurately known ($\pm 1\%$), but the emission per animal error is estimated at $\pm 20\%$. Similarly, the emission factor for coal mines is predicted with an uncertainty of $\pm 13\%$.

Further revisions can be expected in the future, as methodologies for quantifying methane emissions are refined and uncertainty levels reduced. In addition, there are several outstanding issues to be addressed, such as the inclusion of abandoned coal mines, which may substantially affect emission totals.

The high levels of data uncertainty are a cause for concern, as it becomes difficult to quantify emissions reductions. Furthermore, contradictions between the models on which UNFCCC submissions are based and real-world experience are possible. This is particularly important for methane trading, where baselines are set to produce overall GHG emissions reduction targets. Should a project be able to capture more methane than its targets because the targets set are found to be based on



Coal accounts for more than a third of UK electricity generation

Chapter 3. It is clear that if significant and sustained reductions in GHGs are to be achieved through trading then the accuracy of emissions quantification will need to improve across all sectors. This should be made a major focus of greenhouse gas abatement policy.

4.5 UK greenhouse gas emissions

Carbon dioxide makes up the majority of GHG emissions, although production has declined over the past 12 years by 8% largely due to the 'dash for gas': switching to cleaner natural gas combustion (for electricity generation) from the more polluting oil and coal. This has resulted in a cleaner energy supply, but there are signs that carbon dioxide emissions are now rising again due to increased energy consumption. In contrast, methane and nitrous oxide emissions have both declined by approximately 40% in the same period. This has resulted in an overall decrease in emissions from the basket of six greenhouse gases of 15% (Table 10).

Since the Kyoto base year of 1990, UK methane emissions have fallen by 1.57 Mt from 3.67 Mt to 2.09 Mt, equivalent to 33.0 Mt CO₂e. This is a drop of 43%, accounting for 30% of GHG emissions reductions since 1990, which dwarfs the 8% emission reductions of carbon dioxide over the same time period. Other greenhouse gases (N₂O, HFCs and PFCs) have achieved similarly high emissions reductions.

The reduction in methane emissions has been a major contributor to meeting targets as laid out by the Kyoto Protocol. However, because almost half of the reduction in methane emissions is due to the closure of coal mines and non-inclusion of emissions from abandoned mines, the 'real' reductions achieved may not be as significant as the UNFCCC submissions portray. This picture will change substantially once a methodology for the inclusion of emissions from abandoned coal mines is agreed and included.

So far, the UK is one of the few Annex I nations to have reduced greenhouse gas emissions over

inaccurate or uncertain data? If so, then that project will be financially rewarded for what is effectively 'hot air'. The presence of 'hot air' in trading systems can cause a collapse of the trading price and ruin the effectiveness of such a scheme for all participants, as discussed in

Table 10: UK GHG emissions 1990-2002 (Mt CO₂e)

	CO ₂	CH ₄	N ₂ O	HFCs	PFCs	SF ₆	Total	% CH ₄
1990	584.0	76.9	67.9	11.4	1.4	1.1	742.6	10%
1995	547.6	64.3	57.0	15.5	0.5	1.3	686.1	9%
2000	542.6	48.8	44.8	9.1	0.5	1.9	647.7	8%
2002	537.4	44.1	41.0	10.4	0.4	1.6	634.9	7%
Decrease 1990-2002	8%	43%	40%	33%	16%	-23%	15%	30%

Note: 1 Mt CO₂e = 21 Mt CH₄

Source: Baggott, 2004⁶³

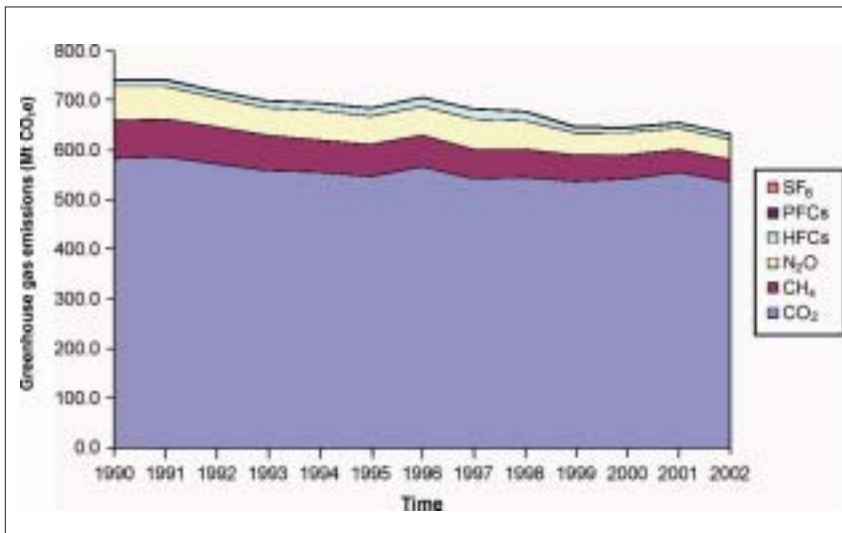


Figure 14: UK greenhouse gas emissions, 1990-2002

Source: Baggott, 2004⁶³

the 1990 baseline (Figure 14). A 13% reduction in 2000⁶⁷ slipped to a 12% reduction in 2001.⁶⁸ Emissions in 2002 did, however, show a maximum observed reduction of 15%,⁶³ but are predicted to rise again in 2003 because of an increase in coal burning in power stations as opposed to gas, due to relative market prices. This has provoked considerable debate as to whether or not emissions reductions will be maintained in the long term and, in particular, whether the UK will meet its Kyoto commitment.

The basis for this scepticism lies in the manner in which emission reductions have been achieved to date. In particular, the majority of emission reductions witnessed over the last decade are not the result of targeted policy. Rather, carbon dioxide emissions were inadvertently cut by an economically-driven shift in the energy resource base, away from a coal intensive industry towards gas-fired and nuclear power. However, such good fortune is unlikely to continue indefinitely: the planned decommissioning of nuclear power stations, along with forecast economic growth and increases in road traffic, are expected to increase carbon dioxide emissions over the forthcoming decades. The UK Government maintain that the Kyoto target will be met, with baseline projections showing emissions to be around 15% below 1990 levels in 2010.⁶⁹ Further

policy measures were introduced in the *Third National Communication*⁷¹ which, if successfully implemented could increase the reduction to 23% by 2010.

However, there is mounting evidence that the UK's efforts to meet the greenhouse gas target are "slipping off track". In any case, DEFRA confess to having long-term concerns regarding UK's greenhouse gas emission trajectory. Baseline projections point to a rise in emissions in the post-2010 period, which by 2020 could leave the UK in breach of current and future rounds of Kyoto commitments.⁶⁹ With the stringent targets set in the 2003 Energy White Paper, the UK has reinforced its commitment to tackling climate change.

The recent increases in GHG emissions due to carbon dioxide need to be addressed by increased energy efficiency, an increase in renewable electricity and reducing consumption from the transport sector. However, due to its high GWP, further reductions in methane emissions still have a significant role to play in meeting short term targets, such as those agreed under the Kyoto Protocol, and may buy time for carbon dioxide abatement and renewable energy technologies to be developed.

Waste and landfill



Waste in the UK is big business: the UK services market for waste management is valued at about £5bn, with the potential to grow to at least £12bn over the next 10 years.⁷⁰ This market, which comprises approximately 0.5% of the UK GDP, involves an estimated 3500 firms.⁷¹ Each year, over 400 Mt of waste is produced in the UK alone,^{65, 70, 72} most of which ends up in landfill sites. By far the majority of this waste (~370 Mt) arises from agriculture, the mining and quarrying industry, and the construction and demolition industry^{73, 74} (Figure 15). Landfill sites account for 22% of UK methane emissions (0.46 Mt).

In terms of methane production, the critical factor is the amount of *biodegradable* waste sent to landfill sites. Municipal waste (from households and small businesses), although only a small proportion of total waste production, comprises the most biodegradable matter and therefore generates the most methane. Both agricultural waste (Chapter 6) and sewage sludge can be highly biodegradable. Sewage sludge is not considered here since it represents less than 1% of total waste generated. The other waste streams contain only a minute fraction of biodegradable material. Therefore the main focus of this chapter is municipal waste.

The generation of methane from

biodegradable waste in landfill is the most complex of all the sectors explored in this report. The quantities of methane arising depend on the qualities and quantities of waste and the waste disposal methods chosen. The proportion of methane captured, rather than emitted to the atmosphere, is dependent on the landfill cap technology employed. Furthermore, any methane captured may be burned to generate heat or electricity. In the latter case, the methane counts as a renewable energy resource and is eligible for valuable Renewable Obligation Certificates. The challenge is to find the optimum balance between environmentally benign waste disposal practices, renewable energy generation and minimising GHG emissions to the atmosphere. This poses a host of challenges at the waste-energy-climate change interface.

5.1 Methane from landfill

The production of methane in landfill is a result of the restricted availability of oxygen during the decomposition of organic waste. Many modern landfill management practices aimed at improving safety and environmental control have paradoxically accentuated the generation of methane by restricting airflow to the site. Improving aeration can reduce methane production, as has been successfully practised in Japan, although this process is energy intensive. Also, the introduction of air into landfill creates an explosion hazard, if oxygen concentrations are too high, and a greater risk of fire due to the higher temperatures reached by aerobic decomposition processes.⁷⁵

The amount of methane emitted to the atmosphere depends almost entirely on the design and management of the landfill and the quantity of biodegradable waste entering the landfill. Unchecked, the landfill gas will migrate through the site in response to gradients of pressure or gas concentration, or simply along paths of least resistance. The gas may migrate through the waste (depending on its permeability) or through cracks and fissures in

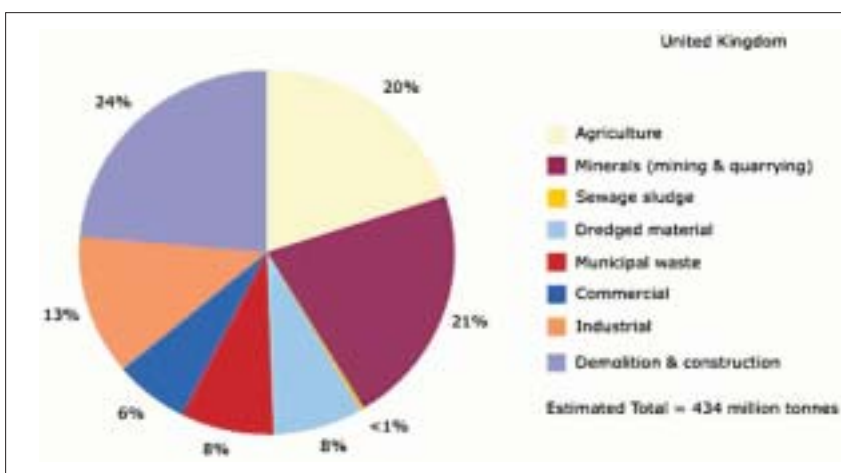


Figure 15: Estimated annual waste by sector (by mass)

Source: DEFRA, 2003⁶⁵

the compacted waste or bedrock material. In the absence of obstacles, such as impermeable liners along the landfill perimeter, the gas can travel considerable distances from the boundary of a site, for example, along buried utility installation routeways (*i.e.* pipes for water, gas or sewage, or channels for electricity and telecommunications cables). Similarly, the propensity for migration to the atmosphere depends largely on the permeability of the landfill cover. Sand and gravel caps will do little to impede vertical migration of the gas, whilst more impermeable silts and clays can successfully restrict this movement. However, any weaknesses within the capping layer will be readily exploited.

In a modern, well-engineered landfill, deposited waste is mechanically compacted to eliminate voids and then sealed with a low-permeability capping layer, usually clay. This process restricts the availability of oxygen within the site, so that, once capped, the majority of waste decomposition is carried out anaerobically. The resultant landfill gas typically consists of

between 40 to 60% methane (by volume) with the remainder being mainly carbon dioxide and a host of trace constituents. The actual composition of landfill gas is dependent upon a number of factors, most importantly the degradable organic carbon content of the waste and the speed at which the material degrades. The composition also changes over time as biochemical conditions alter during the process of decay.

Laboratory studies have identified five main stages in the process of waste decomposition and the process is relatively well understood⁷⁶ (Table 11). Methane production is variable over these five phases and, even within the methanogenic phase, production of methane depends upon the mix of easily digestible biodegradable material versus harder to digest materials such as wood. Some carbon based materials will not decompose and will remain in the landfill. It has been estimated that 6.6 Mt of the 18.6 Mt of carbon going to landfill remains and is sequestered there.³²

Because the emissions of methane are so

Table 11: Methane formation in landfill

<i>Phases</i>	<i>Description</i>	<i>Time</i>	<i>Gases</i>
Phase 1 Initial adjustment	Aerobic phase where easily degradable organic matter is decomposed in the presence of oxygen (from air trapped in landfill), resulting in CO ₂ generation.	Days to a month	CO ₂ increases O ₂ & N ₂ decrease
Phase 2 Transition phase	Oxygen is depleted and anaerobic conditions begin to develop. CO ₂ is produced as complex organic compounds undergo hydrolysis and acid fermentation.	2 weeks or more	N ₂ & O ₂ decrease CO ₂ , H ₂ & H ₂ S increase
Phase 3 Acid phase	Hydrolysis converts organic matter to intermediate compounds, including acetic acid and volatile fatty acids. Acids accumulate in leachate. Methanogenesis begins.	3 months or more	CH ₄ produced. H ₂ & CO ₂ reach maximum concentration
Phase 4 Methanogenesis	Hydrolysis continues and methanogens proliferate. Methanogens convert acids, H ₂ and CO ₂ into methane. For slowly biodegradable organic compounds (e.g. cellulose from paper and wood) this process continues for many years.	May be as long as 30 years	CH ₄ production increases H ₂ & CO ₂ decrease
Phase 5 Maturation phase	Readily available biodegradable material has been converted to methane and carbon dioxide, and emissions decrease. Air diffuses back into landfill.	Decades	CH ₄ & CO ₂ decrease N ₂ & O ₂ increase

Source: Ong, 2003⁷⁶

variable over time, it is exceptionally difficult to predict how much methane is produced by landfill. Whilst it is easy to measure the quantity of gas captured, estimating the amount of methane lost to the atmosphere through the cap is much more difficult, as it is impossible to predict accurately how much methane is generated. Furthermore, the quantity of methane escaping to the atmosphere is not simply the difference between production and capture; some methane may be oxidised in the capping layer through contact with low-affinity methanotrophic bacteria, particularly close to the surface of the site. Such contact can reduce methane content through oxidation to form carbon dioxide, although the importance of this in reducing overall emissions is unclear.⁷⁷

5.2 Landfill in the UK

The current dominance of landfill in the UK is a result of economics, geography and advances in construction and maintenance. Due to the hydrology and geology of England and Wales, this option is more economically favoured as a waste disposal option compared to elsewhere in

Northern Europe.⁷⁸⁻⁸⁰

Over the last six years, the amount of waste sent to landfill has stayed roughly constant, whilst recycling or composting has more than doubled (Figure 16). Around 75% (34 Mt) of municipal waste is sent to landfill each year by the devolved administrations, with the remainder incinerated, recycled or composted. This is estimated to contain more than 21 Mt of biodegradable matter, based on the assumption that between 60 to 70% of municipal waste is biodegradable.⁸¹⁻⁸⁵

There is uncertainty around the exact number of landfill sites in the UK, estimated to be around 1500¹⁵⁶. In England and Wales there were 2,300 working landfill sites in 2003, a fall from about 3,400 in 1994, although newer sites are larger. It is estimated that the total area of land taken for landfill sites is about 28,000 hectares – almost 0.2% of the land area of England and Wales.

Landfill policy

The primary focus of waste policy in both the UK and EU has been on waste reduction rather than specifically targeted at methane. The main policy in the UK to date with regards to landfill has been the Landfill Tax, which centred on diverting waste away from landfill. Whilst such policy has influenced methane emissions to a certain extent, a more coherent and focused approach addressing methane emissions abatement directly is likely to be more effective in this area. The EU Landfill Directive represents a move in this direction, supported by the IPPC Directive (see below).

The waste management hierarchy (Table 12) is a central feature of European waste policy and, as such, has been adopted by the UK. This approach prioritises elimination and prevention of waste over minimisation, re-use, recycling, recovery, treatment and disposal. Moving up the hierarchy leads to more sustainable methods of waste management and increases the possibilities for reducing methane production. The hierarchy has, however, been criticised for not necessarily

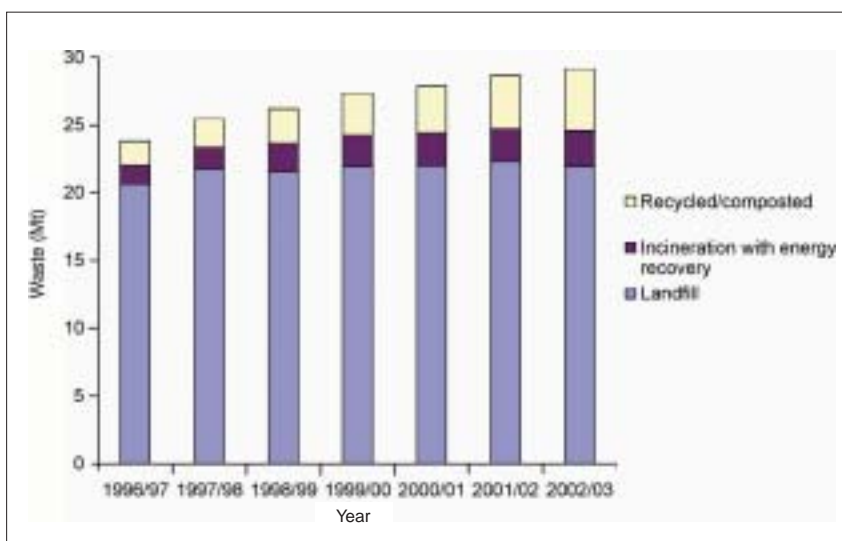


Figure 16: Disposal methods of municipal waste, England, 1996-2003

Source: DEFRA, 2004⁸⁶

Table 12: The waste hierarchy and options for dealing with biodegradable matter

<i>Level</i>	<i>What this means for biodegradable waste</i>	<i>Responsibility</i>
Reduce	Home composting Less packaging Lower consumption	Individuals
Re-use	Reusable packaging	
Recycle	Recycle paper and cardboard wastes	
Recovery	Obtain maximum energy from waste Combustion of methane from anaerobic digesters Incineration with energy recovery Combustion of methane from landfill	Local government
Treatment	Incineration without energy recovery	
Disposal	Landfill	

reflecting what is best for the environment.⁸⁷

Certainly the relative merits of landfill and incineration, with and without energy recovery, are unclear.

Current waste management practices within the UK, with heavy reliance on landfill, are weighted towards the bottom of the hierarchy; generally the least environmentally friendly but most cost-effective and easiest waste management options for the local authority.

It is difficult to deliver waste strategies that focus on the top levels of the waste hierarchy. Successful implementation of such policies requires large-scale social change; many thousands of people each altering their personal waste disposal habits to a more environmentally benign method. Whilst some will be enthusiastic about such issues, achieving a widespread conversion is an uphill battle requiring resources and education.

UK Landfill Tax

The Landfill Tax was introduced in the UK in October 1996 and is levied on disposal of waste to landfill, with very limited exemptions, operating on the 'polluter pays' principle.⁸⁸ It intends to promote diversion of waste from landfill through increasing the economic viability of sustainable

waste practices, such as re-use, recycling and composting, by imposing a tax on landfill waste.

Landfill operators are liable for the tax on all consignments of waste accepted for landfill disposal. In practice, the costs are passed through the waste management chain and the landfill operator pays the levy to Customs & Excise. Introductory tax rates were set in 1996 at £7 per tonne of active waste (mainly biodegradable waste), and £2 per tonne of inactive waste. The Landfill Tax 'escalator' was announced in the 1999 Budget. This raised the standard rate to £10 per tonne and included a commitment to increase it by £1 per tonne each year to £15 per tonne by 2004-05⁷⁹ and by at least £3 per tonne each year thereafter, towards a rate of £35 per tonne in the medium to long-term.⁸⁹

Has the Landfill Tax been effective?

To date, there is still confusion over the effect of the Landfill Tax: the reduction in waste going to landfill has not been documented and there is no quantification of the amount of waste diverted. What is available is a measure of the amount of tax raised and fiscal contributions through the Landfill Tax credit scheme, which offsets waste going to landfill via investment in sustainable waste projects. In 2001/2, over £500M of Landfill Tax was generated, net of the contribution to the credit scheme,⁹⁰ representing almost a five-fold increase since introduction. However, despite the tax, there has been a rise in the amount of waste sent to landfill over the same period: in England, municipal waste increased from 20.6 million tonnes in 1996/97 to 22.1 million tonnes in 2000/01.⁹¹ This puts into question the real effectiveness of the Landfill Tax as a policy instrument.

In 2000, the DETR⁹⁷ claimed the tax was already having a "notable impact" on waste management practices and a consultation paper⁹⁸ stated that the tax "is already encouraging some waste minimisation, re-use and recycling". On the contrary, a review of the UK Landfill Tax in 2002, commissioned by DEFRA,



Municipal waste has increased in quantity by approximately 3% per annum since 1996/7 – faster than the corresponding increase in GDP

suggests that the tax plays a limited role in encouraging people to recycle and compost and is “largely irrelevant” in helping the UK achieve the targets set out by the Landfill Directive.⁹² The ineffectiveness of the tax to stimulate changes in behaviour has been attributed to its low level.⁹³⁻⁹⁶

The EU Landfill Directive

The EU Landfill Directive 1999/31/EC, which was adopted into UK domestic legislation in 2002, is the most explicit policy addressing the reduction of methane generated by landfill. It takes a dual approach, aiming to decrease reliance on landfill as a method of biodegradable waste disposal coupled with requirements to install best-practice methane recovery technologies. The Directive makes it clear that landfill is the least preferred method of waste disposal, with an emphasis on moving up the waste management hierarchy towards reuse, recovery and recycling. Compulsory installation of gas collection and disposal systems is stipulated, with emphasis on energy recovery at new landfill sites. The Directive also prohibits disposal of liquid wastes, tyres and clinical wastes to landfill and distinguishes between hazardous and non-hazardous landfill.

The long-term objective of the Landfill Directive is to reduce methane emissions at

source by diverting biodegradable waste away from landfill. The Directive provides a series of targets that require reductions in the amount of biodegradable municipal waste sent to landfill. These targets have been agreed by the UK Government and Welsh National Assembly, although, since the UK is heavily reliant on landfill to dispose of its waste, it has been given an extra four years by the EU to meet the requirements of the Directive.⁸² This means that the UK is required to reduce the amount of biodegradable waste to landfill to:⁹⁹

- 75% of that produced in 1995 by 2010;
- 50%, by 2013;
- 35%, by 2020.

For the UK, this equates to a maximum of 13.1, 8.7 and 6.1 million tonnes of municipal biodegradable waste to landfill in 2010, 2013 and 2020 respectively.⁸² These dates include the four year extension, which the UK is to adopt for the first two target years with the decision still to be made on the final target year.¹⁰⁰

IPPC Directive

The European Integrated Pollution Prevention and Control (IPPC) Directive 96/61/EC provides further support for the reduction of methane emissions from landfill. The IPPC Directive was implemented in England, Wales and Scotland through the Pollution Prevention and Control Act (PPC) in 2000. Industrial activities subject to control under the PPC regime include certain waste management operations. The PPC demands that operators show they have systematically developed plans to apply the best available technology to prevent pollution or, where that is not practical, to reduce it to an acceptable level.

5.3 Methane capture

Under the EU Landfill Directive, from 2002, all new landfill sites are required to capture the methane produced, with energy recovery being

the preferred option. A recent study has found that the largest factor in the mitigation of methane from landfill is through methane capture, rather than diversion or recycling, due to the quantities of waste already in landfill sites.¹⁵⁴ Historically, control of methane at landfill sites was driven by safety concerns, rather than active GHG emission control, due to the flammable nature of the gas. The most basic systems merely attempt to control the movement of the gas, with the aim of avoiding lateral migration, thereby avoiding the risk of fire and explosion at nearby facilities. Such systems comprise impermeable liners and a capping layer (usually clay), often coupled with trenches or wells, which provide convenient 'vents' through which gas can escape to the atmosphere.

Technologies have become increasingly sophisticated over the past two decades. In particular, the integrity of impermeable liners and capping layers has been vastly improved and these are now considered a fundamental component of landfill design. Improved landfill caps on new sites are the main driver behind the 61% reduction in methane emissions from landfill between 1990 and 2002 (Table 8). Additionally, a variety of systems have been developed which not only control, but also capture, landfill gas. These more advanced gas control systems operate using a network of pipes, wells, fans and/or vacuums to provide a favourable migration route to a common end point. Once collected, the gas can be disposed of by flaring or recovered for its energy value – it is a valuable fuel which has added value due to its classification as a renewable energy source under the Renewables Obligation and so any electricity generated is eligible for ROCs. It is estimated that around 63% of landfill gas is currently flared or utilised – this is forecast to rise to 72% in 2005.¹⁵⁵

Flaring

Flaring involves the collection of gas into a chimney, where it is ignited in order to oxidise methane to carbon dioxide prior to emission.

Flares are the simplest technology for the prevention of methane emissions to the atmosphere and are of two types: 'open flame' and 'enclosed flame'. In an 'open flame' flare, the gas is simply combusted on top of a flame burner, with oxygen coming from the atmosphere. Such combustion is largely uncontrollable and will result in sub-optimal oxidation of the methane and therefore emission to the atmosphere. Conversely, in an 'enclosed flame' flare, the gas is combusted in a chamber with both landfill gas and airflow controlled to ensure optimum efficiency (in excess of 99%) of methane combustion.²⁶

All flares require a minimum concentration of methane to operate. Stable ignition requires a methane content of between 30 and 60%, although special flare designs can accept lower methane concentrations of 5-15%.⁷⁵ Methane concentrations may be too low for the flare in the early and late stages of a landfill's lifecycle, and also possibly at intermediate times due to variable gas production rates over time. Under such circumstances, the flare can be primed with natural gas or propane, although the GHG consequences of this are not ideal.⁷⁵

Energy recovery

Energy recovery is the conversion of waste to produce useful heat or electricity. The methane content of landfill gas makes energy recovery a desirable option. One tonne of biodegradable waste is thought to produce between 200 and 500 cubic metres of landfill gas with a calorific value of up to 20 MJ per m³ (5.5 kWh/m³).¹⁰¹⁻¹⁰³

In order to exploit this resource effectively, a site must fulfil a number of requirements. In particular, a site must generate a sufficient quantity of landfill gas to make methane combustion economically viable, which means current projects are restricted to sites in receipt of relatively large quantities of biodegradable waste. The methane content of the gas must be relatively high (at least 40%) and also consistent, as fluctuations in methane concentrations can



One million tonnes of landfill waste will be adequate to generate 1MW of electricity for 10 years

cause severe operational problems. In order to avoid large variations in methane concentrations, collected gas must be closely monitored and adjustments made accordingly. For example, over-pumping could introduce air into the landfill site, reducing methane production. It is possible to optimise a site for landfill gas utilisation, since factors such as landfill temperature, moisture content and pH can have a large impact on the rate of landfill gas generation and composition. Development of techniques such as recirculation of landfill leachate also have the potential to increase rates of waste decomposition and gas generation.⁷⁷ If successfully implemented, such developments will improve the viability of landfill gas utilisation and may, in particular, improve the prospects for projects on smaller sites.

Landfill gas is considered a renewable energy resource¹⁰⁴ and therefore displaces greenhouse gas emissions from energy derived from fossil fuels. There are three main methods of utilising landfill gas for its energy value: direct use, electricity generation and purification. A fourth option, the use of fuel cells, is still a relatively new and expensive technology, but may become more viable in the future.

Direct use

The direct use of landfill gas as a fuel (to generate heat) is the most efficient energy recovery option, utilising over 80% of the calorific value of the methane. Piping the gas over long distances has proven problematic and costly, therefore the gas is most commonly piped directly to a local heat-intensive industry, such as fuelling kilns, boilers or furnaces. However, since landfill sites are typically located away from population centres due to the unaesthetic nature of waste disposal, they are rarely located near such industrial sites.

This practice has worked best if the producer of the landfill gas is also the user, so that supply and demand are closely matched.

Electricity production

Landfill gas can be combusted to drive engines or turbines for electricity generation. Fuel conversion efficiencies typically range from 26% (for gas turbines) to 42% (for dual-fuel engines), which are comparable to conventional gas-fired power stations. Production capacity varies from a few kilowatts (kW) to several megawatts (MW).⁷⁵ The electricity generated can then either be used directly or sold to the grid.

Since the 1980s, the landfill gas technology for electricity generation has evolved dramatically and the necessary equipment is now readily available on the market. Landfill gas can also be used to generate combined heat and power (CHP), although this requires a use for the heat close to the landfill site itself.

In 2003, landfill gas generated about 3.27 TWh of electricity,¹⁰⁵ equivalent to 24% of renewable electricity production in the UK and 1% of net UK generation. Landfill gas is by far the largest single source of new renewable electricity (*i.e.* excluding large hydro plants) – by contrast, all the wind farms in the UK generated just 1.3 TWh.

Purification to natural gas quality

Landfill gas can be cleaned to pipeline quality (100% methane) and fed into the natural gas distribution network. This process involves removing the carbon dioxide and trace contaminants from the landfill gas. The high fixed costs of refining equipment and the relatively low value of natural gas have precluded the widespread uptake of this technology.

Fuel cells

A fuel cell is a device which converts a fuel feedstock, usually hydrogen, directly into electrical energy. Fuel cells that operate at high temperatures, namely 'solid oxide fuel cells' and 'molten carbonate fuel cells', can utilise methane directly.

Fuel cells rely on expensive catalysts to function, so the feedstock entering the fuel cell must be free of impurities to prevent poisoning of the catalyst. The purity required, in terms of removing the trace elements, is even higher than natural gas quality, which provides an additional expense. However, fuel cells can operate at low methane concentrations so carbon dioxide removal is not a requirement for successful operation.

Fuel cells are currently expensive and only a few pilot projects exist for converting landfill gas to electricity. However, they do offer some significant advantages over other technologies. The efficiency of fuel cells is currently around 40%, which is higher than conventional heat engines. Furthermore, nitrogen from air does not react in a fuel cell, whereas it does in combustion devices, so nitrogen oxides are not emitted. Fuel cells are also a modular technology and so the size of the fuel cell array can be adjusted to suit the output of the landfill over time: as methane emissions decline, fuel cells can simply be removed so that the remaining stack is better matched to the supply of methane. The removed fuel cells can then be redeployed at other landfill sites.

Encouraging capture

Both flaring and energy recovery reap substantial greenhouse gas emission savings by oxidising methane and releasing only carbon dioxide. It is estimated that 1.7 Mt of methane was abated in 2000, forecast to rise to 2.47 Mt in 2005.¹⁵⁵ The degree of savings depends largely on the efficiency of the gas collection system. No system has yet been developed which completely inhibits the release of landfill gas to the atmosphere. In a modern landfill with a comprehensive gas collection system, an average of 85% of the gas will be collected,²⁵ whilst the remaining methane will migrate through the capping layer where 90% will be oxidised by methanotrophic bacteria en route.²⁶ So, at a minimum, methane emissions from new landfill will be just 2% of total generated methane.

Emissions from pre-1996 sites (prior to implementation of 1994 regulations) have been shown to be negligible.¹⁵⁶ However, since landfill sites generate significant methane for 15 to 20 years,¹⁰⁶ post-96 sites which have been closed because they do not meet the regulations may represent an important source of methane emissions. The extent of this issue is unclear: data on the number of landfill sites are uncertain, as are data on methane emissions from these sites. It is difficult to establish a firm baseline for emissions from this sector since methane concentration decreases over time due to natural processes.

In 2002, only 211 landfill sites in the UK extracted landfill gas for energy recovery¹⁰⁷ – a very small proportion, given that there are 2300 working landfill sites in England and Wales alone. The main incentive for methane capture in the UK has been through ROCs under the Renewables Obligation, which has improved cost-effectiveness of landfill gas electricity production. As of June 2002, landfill gas utilisation contracts had been awarded to around 10% of licensed sites in the UK, of which around 60% (201 of 329) were operational¹⁰⁸ (Table 13).

Table 13: Contracts under Renewables Obligation, December 2001

	<i>Capacity (MWe)</i>	
	<i>Projects awarded</i>	<i>Projects live</i>
England and Wales	653.4	384.6
Scotland	40.0	16.6
Northern Ireland	6.3	0
Total	699.7	401.2

Source: DUKES, 2003¹⁰⁵

Further growth is expected in the foreseeable future, encouraged by the Landfill Directive, since the resource potential is far from maximised. In fact, the DTI estimates the UK landfill gas resource to be equivalent to around 6.75 TWh per year, over twice the generation in 2003 of 3.27

TWh, and representing around 2% of present electricity demand.⁸

5.4 Alternatives to landfill

In order to comply with the Landfill Directive, in combination with best-practice methane recovery, alternative waste disposal methods are necessary to reduce reliance on landfill. In effect, this means progressing up the waste hierarchy towards more sustainable waste management options.

UK Waste Strategy

The targets under the Landfill Directive pose a tough challenge for the UK, exacerbated by the current 3% annual growth in municipal waste.⁷⁰ Reducing the amount of biodegradable waste disposed to landfill will require considerable effort by the entire UK waste management chain, including central and local government, waste producers and the general public. Consequently, the UK Government's Waste Strategy 2000⁹⁷ has been developed in accordance with the principles of the waste hierarchy and wider sustainability, with a strong presumption against sending waste to landfill.

Under the Strategy, the Government has established a number of other targets to

complement those for biodegradable waste reduction. In particular, the following targets have been established for the recovery of value from municipal waste, via recycling, composting and other forms of material and energy recovery:

- to recover value from 40% of municipal waste by 2005;
- 45%, by 2010;
- 67%, by 2015.

Recycling and composting

In addition to diverting biodegradable waste from landfill, both recycling and composting enable value to be reclaimed from the waste. Of the biodegradable component, paper, wood and some textiles can be recycled successfully, with the resultant materials used in a range of products. Food, garden waste and cardboard can all be composted, with the residue forming a valuable organic fertiliser.

Neither recycling nor composting avoid greenhouse gas emissions. However, if managed well, both options offer significant advantages over landfill. Whilst recycling demands a significant energy input, the associated greenhouse gas emissions are relatively low when compared to those offset from both the production of virgin materials and disposal of materials to landfill. Recycling is also pivotal to resource conservation.

Composting is a largely aerobic process, meaning that the major by-product of waste decomposition is carbon dioxide. The majority of the carbon remains within the compost, hence giving it high value as an organic fertiliser. However, the process must be well managed, with the compost well mixed and regularly turned to ensure sufficient aeration, else methane can be generated under anaerobic conditions. Composting has the advantage of being feasible on a local level, for individual households, or as community compost schemes. Large scale, centralised composting systems tend to be mechanised, although the sophistication of the system can vary markedly. Highly complex

The UK has a target to recycle and compost at least 33% of household waste by 2015



systems may have the capacity for up to 100,000 tonnes of organic waste per year.¹⁰⁹

Both composting and recycling depend upon separation of the waste. At the household level this may require significant education of the public, whereas on larger scales, labour is required to perform an often unpleasant task. However, mechanical biological separation schemes (see below) may offer a viable alternative that does not require separation of the waste stream.

Current situation

Recycling rates in the UK are currently amongst the lowest in Europe at 9%,⁹⁷ although they are increasing. Large scale waste composting is growing at an exponential rate and doubled in size in the two years to 2002.¹¹⁰ Individual households have practised small-scale composting for many years and the UK Government is encouraging this on a wider scale.

Under the UK Waste Strategy, there is particular emphasis on improving recycling rates in the UK. These efforts have included a focus on producer responsibility, particularly with regard to paper and packaging waste. Regulations have been introduced which specify targets for the recovery and recycling of packaging waste.¹¹¹ This is supported by the 1994 EU Packaging Directive, which aims to pass the responsibility for packaging waste onto the producer thus providing an incentive to minimise such waste.

The Government has also been working with the Newspaper Publishers Association to increase

the recycled content of newspapers, which had increased from 28% in 1991 to approximately 54% in 1999. Targets were introduced to increase this to 60% by 2001, 65% by 2003 and 70% by 2006. The 2001 and 2003 targets were both met ahead of schedule.¹¹² The Government is also working with the Direct Marketing Association and other trade bodies to reduce the quantity of junk mail, which had more than doubled between 1990 and 1999, from 1.5 to 3.3 billion junk items per year.

Energy from waste

Energy from waste (or incineration) is seen as a key technology for diverting waste away from landfill sites and is widely used throughout Europe. It is a well-developed technology, cost-effective and makes use of the calorific value of the waste material.

Energy from waste does not require the separation of waste prior to treatment and, once burned, the original volume of the waste is typically reduced by around 70%.²⁶ The inert ash residue is suitable for landfill and in some cases may be recycled (*e.g.* for road surfacing). Energy can also be recovered from the incineration process for district heating or electricity production. Interestingly, electricity generated from incinerating mixed (biodegradable and non-biodegradable) waste is not eligible for ROCs, whereas energy generated from landfill methane from the same initial waste feedstock is eligible¹¹³ (Table 14). However, electricity from waste incineration is exempt from the Climate Change Levy.

The combustion of waste in incinerators does not produce any methane, since carbon dioxide is the main by-product of any efficient combustion system. There has been concern about emissions to the atmosphere of heavy metals and dioxins from municipal solid waste incinerators.^{114, 115} The introduction of the Waste Incineration Directive 2000/76/EC alleviates this concern as it sets stringent operating conditions and minimum technical requirements for waste incineration and co-incineration. The Directive is aimed at

Table 14: Financial incentives for electricity generation from waste streams

<i>Technology</i>	<i>Useful output</i>	<i>RO eligible?</i>	<i>CCL eligible?</i>
Landfill	CH ₄	Yes	Yes
Energy from waste	Heat	No	Yes
Pyrolysis	Oils, hydrocarbons, CH ₄	Biodegradable fraction only	Yes
Gasification	CH ₄ , H ₂	Biodegradable fraction only	Yes
Anaerobic digestion	CH ₄	Yes	Yes

Pyrolysis plants are found in Europe but are not yet widespread in the UK



preventing and limiting negative environmental effects of emissions into air, soil, surface and ground-water from the incineration and co-incineration of waste, and the resulting risks to human health.

Current situation

More than 9% of UK municipal waste is dealt with by incineration.¹¹⁶ Energy from waste technologies are almost always used – just 0.3% of waste is incinerated without energy recovery and this value is falling. The UK incinerates a smaller proportion of its municipal waste compared to other European countries, such as Denmark (52%) and France (24%).¹¹⁷

However, despite the introduction of tighter emissions controls, incineration is still socially unpopular in the UK, with incineration schemes attracting widespread opposition, especially at a community level. This makes promotion of incineration schemes a politically sensitive issue.

In addition, since any electricity generated is not eligible for ROCs there is less financial incentive to invest in this technology.

Advanced thermal treatment

Energy from waste is simply combustion of the waste in an excess of oxygen, which generates heat that may be used for electricity generation. However, advanced thermal treatment methods have been developed that also allow value to be recovered from the calorific value of waste materials. Advanced thermal treatment plants are of two types – pyrolysis and gasification – depending on the availability of oxygen and temperatures reached. Pyrolysis heats the waste to approximately 500°C in the absence of air and may be considered analogous to the formation of charcoal. This process produces oils and gas which may then be used as fuels in their own right. Gasification is a higher temperature process (1000-1200°C) which partially combusts

the waste in the presence of some oxygen. This produces hydrogen and gaseous hydrocarbons which may then be combusted as a fuel.

Unlike energy from waste, advanced thermal treatment plants do require the separation of waste prior to entering the plant. Recyclable materials such as glass and metals are removed before entering the plant. Post treatment, the flue gases are scrubbed to remove particulates and higher hydrocarbons before using the gases as fuel. Advanced thermal treatment plants are comparatively small as they deal with only specialised sections of the waste stream. They can also act as a modular component for a larger waste plant, such as mechanical biological sorting plants.

Electricity generated from by-products of the advanced thermal treatment of waste is eligible for ROCs. However, only the fraction generated from biodegradable waste is eligible, so the financial returns will be dependent of the composition of the waste entering the plant¹¹³ (Table 14).

Current situation

There are currently no demonstrated advanced thermal treatment facilities in the UK other than on a pilot scale.¹⁵⁴

Anaerobic digestion

Fully-optimised anaerobic decomposition of waste is possible using purpose-built anaerobic digesters in a process known as biogasification. A wide range of biodegradable waste can be treated in this way, including wastes that are unsuitable for composting, such as meat and cooked food. Typically, biodegradable waste is separated from other material before digestion, either manually or mechanically, although newer mechanical biological separation plants can avoid this requirement.

Anaerobic digesters can reduce the time it takes for waste to fully degrade from a few decades to a few weeks, hence maximising the production of methane over a shortened time

period.²⁶ Because anaerobic digesters are enclosed systems, more methane can be recovered, enhancing the efficiency of the system and allowing maximum value to be recovered from the waste stream. The use of anaerobic digesters also yields a more regular and sustained supply of gas compared to landfill. Between 10 and 50% more methane is produced per tonne of waste (depending on waste composition and digester design) than if sent to landfill, yet emissions are typically 1% or less.²⁶ The gate fees charged for taking the waste are the key economic driver behind this technology. The biogas may be burned as a fuel and is eligible for ROCs, providing an additional financial driver for investment (Table 14).¹¹³ Greater efficiency also means that large areas are not required, although a sizeable industrial-style plant must be built. In addition to the valuable methane, the process also produces a solid digestate, which can be used to improve soil quality, and a nutrient rich liquid residue, which can also be applied as a fertiliser.

Current situation

In contrast to countries like Denmark, which uses anaerobic digestion to treat about 1.1 Mt of waste per year, this method is less common for waste disposal in the UK.¹¹⁸ Sewage sludge and agricultural wastes have been treated by anaerobic digestion for several years, but the process is now slowly extending to municipal solid waste with a small number of plants in operation, each of which can handle approximately 260-300 tonnes of waste per year.¹¹⁸ Encouragement to invest in such schemes already exists in the form of the waste gate fees and ROCs.¹¹³ However, as a relatively unproven technology in the UK, additional support through grants or subsidies may be necessary to stimulate the market.

Mechanical biological separation schemes

Several commercial mechanical biological separation schemes have been developed in the UK to recover value from all parts of the waste

stream. In each case, the initial stage is to shred the municipal waste into small pieces. Biffa's integrated waste management process separates the biodegradable waste at this stage and sends it to an anaerobic digester. Conversely, Shanks' Intelligent Transfer Station passes all waste into an aerobic digestion chamber, which rapidly degrades biodegradable waste. Value is recovered from the rapidly biodegradable component in the form of methane and then energy. The waste material from both systems is dry, clean and sterile and can be sorted into component materials, with ferrous and glass materials recovered for recycling. Approximately 50% of the waste material, mainly cardboard and plastic, is only slowly biodegradable and is not removed by the digestion process. This material has a high calorific value and can be used as a secondary fuel in fossil fuel combustion plants capable of co-firing, where it counts as a renewable energy resource (as far as the UK's 10% target is concerned) and is exempt from the Climate Change Levy. Renewable Obligation Certificates can also be obtained if the plastic portion of the fuel is not too high.¹¹⁹

Current situation

As with anaerobic digesters, there are only a few of these schemes currently in operation in the UK. Gate fees and ROCs could provide the incentive for further investment in this area. This method of waste disposal is highly flexible and will be able to cope with the changing waste composition over the next 20 years.

5.5 Recommendations

Data uncertainties

Landfill sites are a major source of methane emissions, with significant methane generated for at least 15 to 20 years at any one site. However, there is uncertainty as to the extent of this problem due to lack of data on the exact number of landfill sites in the UK and associated

methane emissions. Although it is impossible to predict how much methane is actually produced within a landfill site, the quantity of gas captured is easy to measure.

A comprehensive inventory of UK landfill sites, both working and closed, detailing the type of capping layer and other methane capturing technologies installed and amount of gas captured, is needed. This is particularly important for older and closed sites which are unlikely to utilise modern technologies and so could represent a significant source of emissions.

Policy

For maximum savings in this area, there needs to be a stronger policy focus on methane mitigation, as in the EU Landfill Directive, rather than relying solely on achieving emissions reductions indirectly through waste reduction policy.

Methane capture

The energy content of waste should be recovered wherever possible. Encouraging and supporting the installation of suitable methane recovery technologies is central to the Landfill Directive. The crucial issue is how this will be implemented in practice. The Renewables Obligation has been a key driver in encouraging energy recovery from methane in the UK by providing an economic incentive to capture as much of the generated methane as possible, relying on market-based mechanisms. This could be underpinned by the provision of grants or subsidies by the Government to encourage the uptake of best-practice technologies.

Lower production volumes of methane from landfill in future years (assuming the Directive is successful) would open up the way for new landfill gas technologies capable of operating at lower concentrations, such as fuel cells, provided there are sufficient economic incentives to attract investment. Grants or subsidies from the Government would encourage the development of such technologies.

Anaerobic digestion of waste generates electricity without any methane emissions



Alternatives to landfill

If biodegradable waste is to be diverted from landfill, as required by the Directive, support must be given to viable alternatives (without associated methane emissions) for the disposal of this waste. Given the political sensitivities around incinerators in the UK and the lack of a strong financial incentive in the form of ROCs, incineration looks to be a less politically favoured method of waste disposal. Anaerobic digesters and mechanical biological separation schemes appear to be more attractive options, with the waste gate fees and eligibility for ROCs providing economic drivers for investment. As with the methane capturing technologies, the introduction of these schemes could be further encouraged through the provision of grants or subsidies.

Waste reduction

Waste reduction still has an important role in reducing methane emissions. The problem here is

not really the lack of relevant policies but merely a problem in implementation of existing policies. The UK Government's primary concern, particularly for municipal waste, is to move up the waste management hierarchy towards waste avoidance and minimisation. This requires action by manufacturers, to reduce packaging, and local councils, working with their residents to achieve widespread changes in lifestyles and attitudes.

Conflict with the Renewables Obligation

In the UK, the Renewables Obligation is one of the key drivers behind investment in methane recovery technologies through the provision of ROCs. However, the Landfill Directive also aims to reduce the amount of biodegradable waste sent to landfill. This will result in less methane being produced and so the financial rewards from generating electricity from landfill gas will be lower. Hence, there is a danger that the incentive provided by ROCs to introduce best-practice

capturing and electricity generating technology at landfill sites will be lessened and other incentives may be needed in the future. However, there will be a significant delay before the impacts of biodegradable waste reduction are felt, since current landfill sites will continue to produce methane for tens of years.

leaks out through the cap – retrofits are not possible. Even if there were methane available to trade, because the market price of ROCs is currently higher than that of methane, obtaining ROCs would be the preferable option, thus removing the incentive to trade.

Trading

Two possibilities exist for trading in the waste sector: trading the actual waste itself and trading of methane emissions from landfill.

Trading of waste

The opportunity of trading waste is currently under consideration in the UK. The system of biodegradable waste trading is a system, underpinned by the Waste and Emissions Trading Bill, which would enable waste disposal authorities to meet the objectives of the Landfill Directive and thus reduce methane emissions at minimum cost. Operating on a system of tradable allowances, those authorities that exceed their allowances by sending less biodegradable waste to landfill will be able trade the excess allowances with those that send more.¹²⁰ Such a policy tool will certainly help meet the targets set out by other waste policies such as the Landfill Directive.

Methane trading

In terms of trading, the possibilities from landfill sites are limited since methane capture is already required at all sites for safety reasons, with best-practice technology specified for new sites under the Landfill Directive. None of the methane savings would be 'additional' and are therefore not tradable. Similarly, diversion of waste from landfill to reduce methane emissions is not a viable route into the trading process either as this is also required under the Directive. Poor capping technology at older landfill sites may result in higher methane emissions and so any further reductions would count as additional. However, there is no easy way to capture the methane that

Agriculture



Agriculture is responsible for 43% of methane emissions (0.91 Mt) making it the largest methane-emitting sector in the UK.⁶³ Emissions arise entirely from the livestock sector, almost 90% of which are a direct result of the digestive processes in livestock mammals¹²¹ (enteric fermentation). The remaining 10% arises from manure management practices which promote anaerobic decomposition of waste. Non-livestock agriculture is not a measurable source of methane in the UK.

Emissions from the agricultural sector are declining slowly, being 13% lower in 2002 than 1990. This is not so pronounced as emissions reductions achieved by other sectors. As a consequence, the relative importance of methane emissions from agriculture has grown. Policy measures will be required to achieve substantial cuts in emissions, but implementing such policies is a major challenge.

The UK livestock industry has suffered greatly in recent years, with both the BSE (bovine spongiform encephalopathy) and Foot and Mouth crises damaging consumer confidence and profitability of farms. The UK farming industry is regarded by the public as a vital component of

the UK economy, so any policy measures introduced must reflect this and not penalise an already strained industry. Furthermore, there is public mistrust of the effects of agri-technologies and large scale agri-business, as exemplified by BSE, Foot and Mouth, and genetic engineering. Any mitigation measures actively promoted by the Government should reflect these concerns.

6.1 How is methane produced?

Methane emissions from the agricultural sector derive from two sources: enteric fermentation and manure management practices (Table 15).

Enteric fermentation

Methane is produced as a result of the natural digestive processes in ruminant mammals (those that chew the cud), such as cattle and sheep. Unlike humans and other non-ruminant mammals, ruminants are unable to digest their feed entirely, particularly cellulose-based plant polymers, by the action of stomach enzymes alone. Instead, ruminants have an expanded gut (the reticulo-rumen) in which feed is broken down by bacteria and ferments prior to gastric digestion. In an adult ruminant, the rumen comprises approximately 85% of the stomach capacity and typically contains digesta equivalent to around 10-20% of the animal's weight.^{26,123}

Food is retained in the rumen for a considerable period of time where, in the presence of a large and diverse microbial population, it is anaerobically fermented to form volatile fatty acids, ammonia, carbon dioxide, methane, cell material and heat (Figure 17). The balance of these products varies between animals and with dietary intake, being largely determined by the composition and activity rates of micro-organisms present in the rumen. The gaseous waste products are mainly removed by the process of eructation (burping) or eliminated as part of the respiration process.¹²⁴ Less than 10% is emitted as flatus (farts).

Table 15: Methane produced by enteric fermentation and manure management (kg methane per head per year)

<i>Animal</i>	<i>Enteric fermentation</i>	<i>Manure management</i>
Dairy cows	115	13
Beef	48	6
Other cattle > 1yr	48	6
Other cattle < 1yr	33	6
Pigs	1.5	3
Sheep	8	0.2
Lambs < 1 yr	3.2	0.1
Goats	5	0.1
Horses	18	1.4
Poultry	Not estimated	0.1
Deer	10	0.3

Source: National Atmospheric Emissions Inventory, 2004¹²²

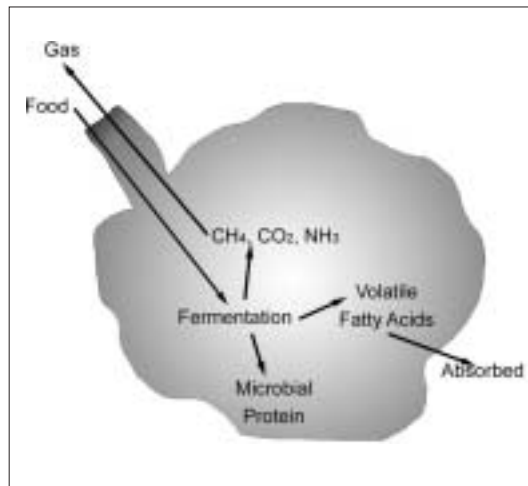


Figure 17: Enteric fermentation in ruminant mammals

Non-ruminant mammals do produce some methane as a result of digestive processes, but at far lower rates. For example, pseudo-ruminants (such as horses) do not have a rumen, yet ferment feed during the digestive process to enable them to obtain essential nutrients from plant material. Mono-gastric animals (such as pigs) also produce small quantities of methane during digestion.

Manure management

Modern manure management systems tend to restrict the availability of oxygen to the waste, promoting the production of methane. Anaerobic manure management is associated with intensive agriculture, particularly dairies and pig farms where large numbers of animals are contained within a single, relatively confined facility. The high density of animals leads to the production of large quantities of waste, which is typically washed out into tanks, lagoons or pits where it is stored as a liquid or 'slurry'. Being liquid, air is excluded and waste decomposition takes place under predominantly anaerobic conditions, resulting in the production of methane.

The amount of waste produced is dependent upon the number and types of animals, along with the quantity and quality of food consumed.

The precise amount of methane produced from any given animal waste is dependent upon a number of factors, most notably the quantity and composition of the waste, which, in turn is dependent upon the type of animal and feeding practices. Ambient climatic conditions are also important. Increased temperature promotes biological activity, thereby enhancing methane production.

6.2 Mitigating emissions from livestock

Emissions from livestock are a diffuse source and as such are not easily captured or quantified. Therefore mitigation strategies for this sector focus on reducing production at source. Methane production from animals is dependent on a number of factors, represented simply as:

$$\begin{aligned} \text{Total emissions} &= \\ &\text{Number of animals} \\ &\times \text{Lifetime of animal} \\ &\times \text{Emissions per head per day} \end{aligned}$$

The overall emissions may be reduced by altering any of the above parameters: reducing livestock numbers, reducing the emissions per animal, or achieving the same product yields over a shorter lifetime. There is a range of management and technological options available, some of which will alter more than one of these parameters at once.

Methane from animals is a waste product, representing a loss of dietary energy available to the animal of 2-12%. As such, the production of methane both directly from enteric fermentation and from the decomposition of organic animal waste, is a reflection of the inefficiency of the digestive process. Consequently, methane emissions can be reduced through productivity improvements, which also offer potential cost-benefits to the agricultural sector. Increased productivity can be achieved through increasing the yield of meat or milk from an animal over the same lifetime, or attaining the same yields in a

shorter lifetime. Both have the effect of reducing the overall methane production per mass of product. This requires nutritional adjustments, such as changes in diet and use of feed supplements, or genetic modifications. These options are discussed in more detail below. However, the applicability of these techniques in practice is limited by a number of factors, namely: risks to human health; consumer acceptability; animal welfare issues (particularly risks to animal health and development); ethical considerations; and cost effectiveness.

Dietary adjustments

Improved nutrition and dietary adjustment in order to optimise rumen and animal efficiency is a growing area of interest in terms of both environmental and productivity benefits. Methane emissions depend on the average daily feed intake and efficiency with which feed energy is converted into product (meat, milk). This in turn depends upon the efficiency of rumen fermentation and the quality of the feed. Improvements to the quality of animal feedstuff, particularly in terms of digestibility and energy value, or improvements to rumen efficiency provide two potential routes to methane reductions.

Feed quality

Feed conversion efficiency – the rate at which feed energy is converted into product rather than waste – is higher for certain types of feed. For example, grain feeds are converted more efficiently than forages (grass), as they are relatively easy to digest and have a high energy content.

Rumen efficiency

Efficient digestion requires a diet that contains essential nutrients for the fermentative micro-organisms. If nutrients such as ammonia, sulphate and phosphate are limited, digestive efficiency will diminish, resulting in increased emissions of methane. Nutritional supplements

can therefore be used to enhance dietary nutrition. In some cases this has resulted in increased milk yields of 20-30% and increased growth rate of 80-200%,²⁶ with typical methane reductions of up to 40% per unit output. The largest gains from nutritional supplementation are likely to be amongst animals on low quality feeds: in tropical areas with chronic feed constraints, supplements can result in emission reductions of up to 75%. In the UK, where ruminants have relatively high quality diets, this potential is more limited. Nevertheless, a number of advanced supplements, in the form of chemical and pharmaceutical additives, have been developed which have the potential to deliver further efficiency or productivity improvements. This may not prove a popular option given the growing consumer backlash against the use of chemical additives in recent years and a number of such substances have already been prohibited from use in the EU and elsewhere.

The extent to which dietary adjustments and supplements could achieve methane reductions in practice is largely dependent on the real and perceived risks to human and animal welfare, along with the economic cost.

Genetic improvements

Selective breeding can result in significant improvements to the genetic characteristics of ruminants, such as digestive efficiency and productivity, although developments have been hindered by associated problems with fertility, lameness, mastitis and metabolic disorders.²⁶ Arguably, greater scope exists with improvements to reproductive efficiency, which could significantly reduce the large numbers of animals which typically comprise a reproductive herd. The UNFCCC (fact sheet 271) reports that pilot projects in India have achieved increased birth rates as a result of improved feeding practices: the interval between births was reduced by almost half, from 24 months to 12-15 months. There have also been suggestions that genetic engineering could achieve methane reductions from ruminants by



There is widespread opposition to genetic engineering in the food chain

increasing fermentation efficiency through adjustments to rumen micro-organisms.

However, there remains strong public resistance to genetic engineering in the food-chain due to both ethical objections and scientific uncertainty regarding associated risks and knock-on effects.

Reducing livestock numbers

Fewer animals will result in a reduction in methane emissions from both enteric fermentation and manure management. However, this is a highly contentious and politically troublesome option, especially after the BSE and Foot and Mouth crises have strained the UK livestock farming industry. Attempts to force a reduction in livestock numbers are unlikely to be successful; in New Zealand, proposals to introduce a tax on livestock to reduce emissions proved so unpopular the measure was withdrawn. Any drop in numbers would also need to be matched by a corresponding drop in consumer demand for meat and animal products, otherwise production and methane emissions will merely be displaced to other countries.

There are signs of a shift in consumer preferences with a change in demand for meat and animal products. Within the UK, as well as a number of other European countries and the USA, there has been a noticeable move away from red meat towards poultry, along with a growing vegetarian movement and support for organic produce. Whilst this has been greeted

optimistically by some in terms of the wider implications for sustainability, including potential greenhouse gas emissions reductions, the true benefits remain unclear. In particular, the stability of this trend, the wider implications for the economy and agricultural sector, and the complex knock-on effects for the environment and sustainability are uncertain. Because of the relative emissions factors (Table 15), minimising consumption of dairy products is more significant than minimising meat consumption, in terms of greenhouse gas emissions. However, this would be a difficult area to legislate.

Organic farming requires lower livestock densities through tighter controls on animal welfare standards. An *individual* farm turning organic would therefore have to reduce stock numbers to comply with these standards, but would retain income due to the premium paid by consumers for organic produce. However, this may not reduce livestock numbers across the whole agricultural sector if other farmers increase their herds in order to supply the same level of consumer demand for meat and milk.

Therefore, neither enforced reductions in agricultural production levels or consumer demand are considered to be realistic or viable routes to long-term methane emission reduction.

6.3 Mitigating emissions from manure management

Reductions in methane emissions from manure decomposition can be achieved simply by modifying waste management practices. Several waste management techniques are available which favour aerobic decomposition.

Dry deposition

The 'dry deposition' (land application) of waste is a widely practised, relatively low-tech option, which enables value to be recovered from waste as a fertiliser. In order to minimise any opportunity for anaerobic decomposition, the manure needs to be spread as soon as possible

following production and collection. The IPCC report that, for the average EU climate, daily spreading of manure results in the release of 0.1 to 0.5% of the manure's methane potential compared to 10 to 35% from conventional manure management practices.²⁶ However, land spreading of waste is not without problems. In particular, this practice is associated with relatively large ammonia and nitrous oxide emissions and risks eutrophication of nearby lakes and rivers from nutrient-rich run-off.

Composting

Composting offers another low-tech option for managing manure. Liquid waste can be dried, making the waste suitable for composting. If necessary, other dry organic material can be added to the waste. However, for air penetration to be maximised, and therefore anaerobic decomposition minimised, the compost must be regularly turned.

In the case of both dry deposition and composting, the complex organic compounds within animal waste are broken down naturally by bacteria, releasing carbon dioxide. This is part of the natural carbon cycle, the carbon dioxide being originally absorbed by the plants used as livestock feed during photosynthesis. However, both techniques are likely to require energy input (for the mechanised processes) and therefore any associated greenhouse gas emissions should be deducted from the total methane savings. These options may not be appropriate because they both require a certain amount of space; methane emissions from manure management are generally associated with intensive farming facilities dealing with large quantities of waste within a confined area.

Aeration of liquid waste

A more practical way of reducing methane production may be through the aeration of liquid waste. By increasing the levels of dissolved oxygen within liquid waste, typically using

mechanical pumps, aerobic decomposition is encouraged. Again, this process requires substantial energy input, with implications for greenhouse gas emission savings. Furthermore, this process has been linked to increased nitrous oxide emissions.

Methane capture

In reality, it is often preferable to capture methane emissions from the manure management practice rather than attempt to prevent them. Technologies to capture and dispose of methane arising from manure management practices are similar to those applied to landfill and have proved highly successful. Waste pits or lagoons can be lined and covered with impermeable materials in order to contain and collect the methane. Whilst this option has the advantage of being relatively low-tech, it does require space and the gas capture rate may be fairly low due to problems associated with sealing large areas.

Anaerobic digestion

A better rate of methane capture is achieved by purpose-built anaerobic digesters, which operate according to the same principles as those used within the solid waste management process, optimising decomposition of manure for methane production and collection. The IPCC report that anaerobic digesters typically release just 5% of the total methane potential of the waste, most of which comes from further decomposition of the waste residue once it has been removed from the digester.

Digesters have become increasingly popular within the agricultural waste sector, bolstered by the range of benefits offered by this technology. By heating the vessel to around 60°C, the production of methane can be maximised over a relatively short period, decreasing retention time of the manure from around 60 to 20 days. The biogas generated can be recovered for its energy value, improving the cost effectiveness of this

practice. The resultant gas comprises approximately 65% methane, which can either be combusted directly as a local source of fuel or else used to generate electricity for use onsite or for sale to the grid. This process ensures that methane is converted into carbon dioxide prior to emission and also offsets greenhouse gas emissions from the equivalent energy supply from coal or oil. Furthermore, the electricity generated is eligible for ROCs, providing an important financial incentive to implement digester technology as well as being an additional revenue stream for the agricultural community.

Other benefits of managed anaerobic digestion include reduced contamination from runoff, removal of noxious odours, lower levels of pathogens and retention of the organic nitrogen content of the manure. This means that the residue is a valuable organic fertiliser. Other products contained within the effluent have been successfully used for animal feed and as aquaculture supplements. Such advantages may make anaerobic digesters an attractive option even if energy recovery is not possible. In these cases, the collected gas can be flared prior to emission, oxidising methane to the less potent carbon dioxide.

The UK's first dung-fired power station is in Holsworthy, Devon. It collects 146 000 tonnes of slurry per year from 27 local farmers and has a capacity of 1.4 MW, with the waste heat used for a community heating scheme. The project was relatively cheap, receiving £3.5m in EU grants, coupled with matched funding from a German biogas company. The intention is to introduce 100 such plants across the UK.¹²⁵

6.4 Existing EU and UK policy

There is currently no agricultural policy in the UK specifically targeted at mitigating methane emissions. Reductions in emissions have been achieved fortuitously through policies aimed at other objectives, such as nitrate pollution and manure management.

Most UK agricultural policy is based on the EU Common Agricultural Policy (CAP). Introduced in the 1960s, the CAP was intended to decrease dependence on imports and deliberately increase domestic food production through a system of subsidies paid to EU farmers. Other mechanisms used by this policy were market management to decrease surpluses, and import taxes and export subsidies to protect the domestic market, thus ensuring food security and a fair standard of living for those dependent on agriculture. The subsidies have resulted in some overproduction, often at the expense of the environment, by encouraging a more intensive form of agriculture and so adversely affecting the amount of methane produced.

The policy is also expensive, costing the EU £28.5bn per year. It has been estimated that every head of cattle in the EU is subsidised by £1.40 per day.¹²⁶ The UK receives 9% of available CAP funds (some £3bn in 2000-2001), but overall is a significant net contributor to the policy.¹²⁷

The CAP is currently undergoing major reform¹²⁷ as it is considered unsustainable in its present state. These reforms are unlikely to reduce costs but may decrease methane emissions by reducing livestock numbers. The EU has suggested 'decoupling' direct payments to farmers (or separating payments from production) so that farmers are encouraged to farm for market demand rather than the subsidies available. Removal of subsidies should lead to higher prices and preserve farm income. Studies investigating the impact of decoupling indicate that the recent proposals will result in reduced agricultural production and livestock numbers.¹²⁸⁻¹³⁰ A further reform of arable and dairy market regimes will reduce intervention price support while partially compensating farmers for income loss through increased direct payments.¹³¹ This is likely to further reduce livestock numbers and therefore methane emissions.

Another policy that influences emissions from the agricultural sector is the Integrated Pollution Prevention and Control (IPPC) Directive discussed

in Chapter 5. This Directive extends the pollution control regime to the UK agriculture sector by covering intensive pig and poultry installations. Again, this policy does not specifically target methane, its focus being more on reducing ammonia, but since it covers manure management and production, it will also have some impact on methane emissions.

6.5 Recommendations

Whilst the agriculture sector is responsible for the majority of methane emissions in the UK, it is also one of the most difficult in terms of emissions reduction legislation, reflected in the current lack of such policies.

Emissions from livestock

Methane capture is not a realistic option for livestock emissions. Of the options for reducing emissions, neither lowering livestock numbers nor promotion of agri-technologies appear to be particularly attractive or feasible politically. Policies must be acceptable to the UK farming industry and publicly acceptable in terms of food safety and other environmental issues.

Reducing livestock numbers via direct policy measures would be unacceptable to the farming industry, who would view it as a loss of income. It is possible that the CAP reforms may help to reduce livestock numbers through the removal of subsidies thus preventing overproduction, although to what extent is unclear.

The current social trends towards organic produce, lower meat consumption and vegetarianism could help underpin any reductions in animal numbers, although they are unlikely to be major factors by themselves. Such trends could be encouraged through educational programmes focused on lower red meat and (especially) dairy consumption, linked to the corresponding environmental and greenhouse gas benefits.

Organic farming is a farming system that best addresses many policy objectives for agriculture and has a strong growth potential given continuing consumer demand. Supporting a move towards more sustainable methods of farming may help towards decreasing livestock numbers.

Policies encouraging emissions reductions through improving livestock productivity and efficiency may find support amongst the agricultural community due to increased profits. However, such policies are unlikely to be popular with the public, who, in general, wish for a more natural form of agriculture with a minimum of chemical or biotechnological inputs into the food chain. The widespread rejection of genetic engineering in this country and Europe, coupled with fears over food safety following the agricultural practices that led to the BSE crisis, mean that any direct promotion of such measures to reduce methane emissions are likely to be viewed with distrust.

Further research is required into the opportunities for productivity increases and methane emission reductions from animal dietary changes. This should be conducted within animal welfare guidelines, taking into account public acceptability of agri-technologies such as genetic engineering.

In essence, as far as agricultural emissions from enteric fermentation are concerned, there is a trade-off to be made. Some reductions will occur as part of the CAP, but any further reductions in methane are likely to be difficult to achieve without alienating the farming community or the general public. Faced with such an impasse, it may be necessary to accept that the livestock industry is sufficiently important to the UK and that a certain level of methane emissions will always be produced by agriculture. This shortfall can be made up by simpler, more cost-effective reductions in other methane generating sectors.

Food supplements and growth hormones can cut methane emissions. But do the public want them?



Manure management

Policies targeted at reducing methane emissions through improved manure management practices are more straightforward. In this case, the methane is capturable and therefore can be used to generate electricity or fuel gas-fired equipment. Best-practice technology exists in the form of anaerobic digesters and a strong financial incentive to support this technology is already available through ROCs.

The main barrier to widespread implementation at present appears to be lack of knowledge about the technology or conservatism within the sector. This could be overcome through education of the farming community about the positive benefits of anaerobic digestion, further supported by grants or long term low-interest loans to reduce the initial costs of capital equipment, similar to those under the Clear Skies Programme. Assistance in setting up farming co-operatives with shared digester facilities would also aid the development of community level anaerobic digestion schemes.

Methane trading

Trading of emissions from livestock is unlikely due to the scattered and diffuse nature of methane producers, making capture difficult. Emissions from this sector are hard to quantify, being based on estimates of emissions factors from different animals and feedstocks. Verifying any emissions reductions would also prove complicated.

A further barrier to trading from the agricultural sector is the small size of players – traders require larger quantities than individual farmers would be capable of producing. Such players would therefore not be capable of participating effectively in a trading scheme, especially the EU Emissions Trading Scheme which focuses on large scale emitters. Some form of aggregation would be necessary, but this would be likely to be so complicated as to be ineffectual.

Oil and gas sector



7.1 Introduction

The oil and gas sector was responsible for 0.39 Mt (19%) of methane emissions in the UK in 2002,⁶³ making it the third largest methane-producing sector. Emissions are from two major sources – venting of methane from rigs and plants during maintenance and leakage from the gas pipeline network. Of these, the latter is by far the most important, accounting for 85% of methane emissions from this sector in 2001.⁶⁸ Importantly, venting from rigs is a point source and therefore capturable, whereas leakage from the pipeline network is a diffuse source of methane and therefore can only be reduced, not captured. This is reflected in the large uncertainties of emissions estimates from pipeline leakage ($\pm 40\%$).

Since 1990, the overall consumption of gas in the UK has nearly doubled, rising from 597 TWh to 1104 TWh in 2003¹⁰⁵ (Figure 18).

The increased throughput of gas since 1990 is mainly due to an increase in gas-fired power stations, rather than an increase in domestic and industrial usage, which have remained roughly constant. With the decline of nuclear power coupled with increased electricity demand, gas is likely to form an increasing contribution to UK electricity generation in the foreseeable future.

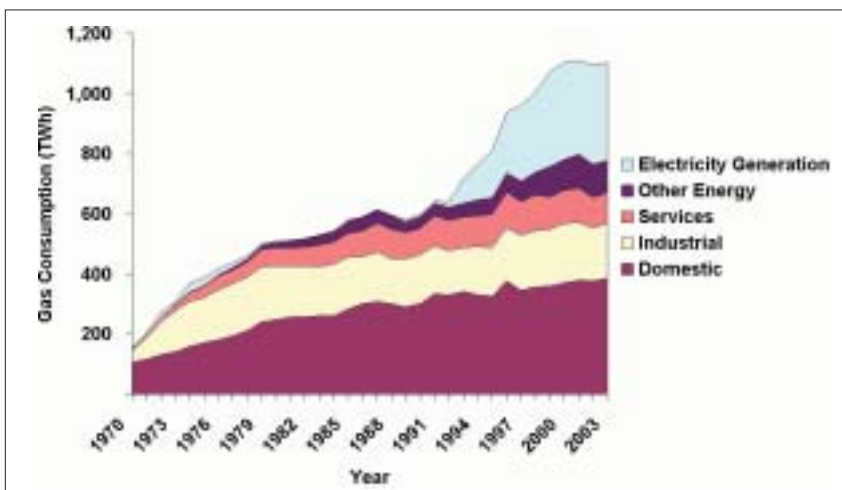


Figure 18: Gas consumption by sector, UK, 1970-2003

Source: DUKES 2004¹⁰⁵

Therefore methane emissions associated with this sector are becoming progressively more significant.

7.2 Sources of methane

Pipeline leakage

In 2003, it was estimated that 4.5 TWh of gas was lost through leakage.¹⁰⁵ Leakage from pipelines is difficult and costly to eliminate. Individual joints, flanges and seals along the distribution network leak frequently and, although not a major source of methane individually, are cumulatively significant over the whole 275,000 km pipe network.⁶² Leakage is greater from traditional cast iron pipes than modern plastic versions.¹³²

Most of the methane leakage, perhaps tens of tonnes per year, is from compressor seals in the boosters which are required every 60-100 miles along the pipe network to maintain pressure for transmission. Valve leakage can be very high in older installations.¹³²

Venting from rigs

Methane may be mined independently as natural gas or alongside oil and coal. In 1998, there were a record 204 offshore oil and gas fields in operation (Figure 19). Of these, 109 were producing oil, 79 gas and the rest condensate (a liquid condensed from natural gas).¹³³ In total, 127 million tonnes of oil and 103 Mt oil-equivalent of natural gas were mined in 2002.¹⁰⁵

When oil is mined from a rig, it contains a mixture of oil, water and natural gas. This is separated on site by passing the mixture into large settlement tanks, where the three fractions separate by gravity. Gas is removed at the top and water from the bottom, leaving just the crude fraction. After repeating this process several times, the oil is of high purity and can be pumped along a pipeline to shore.

When the tanks need maintenance they must be made safe for human activity; methane is both explosive and a non-pungent asphyxiate. The



Figure 19: North Sea oil and gas fields

Source: UK Offshore Operators Association, 2002¹³³

tanks are sealed off and flushed with water, then nitrogen, followed by air. The latter processes purge methane from the tanks, which were historically vented to the atmosphere. This resulted in significant methane emissions, especially due to the high operating pressure. Gas only rigs must also be purged of methane before work can recommence.¹³⁴

7.3 Mitigating methane emissions

Pipeline leakage

As a diffuse source of methane, capture is not an option. Mitigation of methane emissions from the pipeline network can be achieved simply by replacing old cast iron pipes with modern plastic piping. However, this is a laborious and costly process, involving labour-intensive construction work. Despite gains in operating efficiency to be made by minimising leaks, the relatively low cost of gas, especially compared to the cost of upgrades, means there is little economic incentive to do so. Even with the likely rise in gas prices over the coming years as the UK becomes more reliant on fossil fuel imports, fuel price alone is unlikely to encourage network investment.

Venting from rigs

As a point source, capturing methane from rigs is more straightforward. By flaring instead of simply venting to the atmosphere, carbon dioxide is emitted in place of the more potent methane. This tends to be the most common method used to deal with the methane. Alternatively, all greenhouse gas emissions can be avoided by passing the aqueous and gaseous by-products from the tank back into the well during

maintenance, thereby sequestering the greenhouse gases that would otherwise be emitted to the atmosphere. This methane does not remain sequestered: it is mined again when the rig is operational once more.¹³⁴

7.4 Existing UK policies

In the UK, there are few policies or regulations in place that address natural gas leakage from pipes or even leakage monitoring. National Grid Transco operate the pipeline network and are responsible for its maintenance and attending to leaks. Transco spends an average of £600m per year on maintenance, of which £335m is spent on pipeline replacement. Transco is also mandated by the Health and Safety Executive to replace iron pipelines that lie within 30m of any property; a programme that will take place over 30 years. This, however, is a safety issue rather than active greenhouse gas abatement.

Leakage rates from the natural gas transmission and distribution network have improved as a result of a number of efforts: replacing old cast iron pipework, gas conditioning, pressure management and a mains and service replacement programme.^{135, 136} Emissions have reduced by 14% (for the period 1990-2001)¹³⁵ against a target of 20% by 2000 (relative to 1992 levels).¹³⁶ In line with this, Transco revised its internal target to reduce leakage, in absolute terms, by 12.5% from 1990 levels by the year 2010, citing increased throughput as the reason for revision of the 20% target. It does, however, aim to overachieve this target by 7.5% by that date.¹³⁶

Encouraged by the UK Emissions Trading Scheme (UK ETS), significant advances have been made in reducing methane emissions from oil and gas rigs. Companies such as Shell and BP have been able to trade carbon credits gained from capturing methane that would have otherwise been released into the atmosphere.

Both BP and Shell have also developed their own internal trading schemes in advance of both the UK and EU ETS. Pilot trading of greenhouse

Carbon trading has encouraged the capture of methane emissions from oil and gas rigs



gases was started by BP between its own sectors and installations in 1999, going company wide in 2000.¹³⁷ Internal trading allows companies to institutionalise the concept of a cost associated with environmentally damaging emissions, reinforce a culture of environmental accountability and develop trading skills to prepare for the emerging international marketplace. As a business practice it also allows a company to allocate capital to initiatives which have the greatest impact at lowest cost.¹³⁸

7.5 Recommendations

Pipeline leakage

Although leakage rates have reduced over the last ten years, methane emissions from gas pipelines are still significant and becoming more so with the growth in gas consumption. One of the major obstacles to achieving reductions in this area is the poor quality of data. Historically, pipeline leakage has been primarily a safety issue but with

growing awareness about the environmental impact of methane emissions, quantification has become more important. Without a reliable baseline, there is uncertainty regarding the extent of the problem and no standard against which to evaluate any measures taken to mitigate emissions. Therefore, one of the first steps needs to be improved monitoring and data collection.

Regular, cost effective programmes for detecting, prioritising, and repairing leaks across all sectors of the gas industry – production, processing, transmission and distribution – are required. Monitoring equipment could be installed as part of the ongoing maintenance and upgrade of the gas pipeline network with a particular focus on boosters, since this is where the majority of leaks occur. This would enable more effective detection as well as more accurate quantification of gas leaks.

Although leakage represents a loss in revenue to the industry, the relatively low cost of gas means the economic incentive to achieve emissions reductions is weak. Safety tends to be the main concern at present. Minimisation of pipeline leakage is therefore more likely to be underpinned by environmental concerns and implemented through policy instruments rather than on an economic basis.

The industry would benefit from a focus on cost effective technologies and practices that improve operational efficiency and reduce emissions of methane. The USA's Natural Gas STAR Programme encourages the natural gas industry to reduce emissions through market-based activities that are both profitable for industry partners and beneficial to the environment.¹³⁹ This has introduced a range of best management practices to achieve emissions reductions at all stages of the gas production-distribution cycle. Opportunities and options to reduce leaks and venting from the largest sources were jointly identified by EPA and gas industry representatives and it is intended to reproduce these solutions across all sectors.

Trading could prove a strong driver towards

lower methane emissions provided additionality of the savings can be shown. Those reductions already required through legislation under the Health and Safety Executive would not qualify as additional and therefore could not be traded. Also, the lack of reliable data means there is a risk of introducing 'hot air' into the trading scheme where the gas industry could be rewarded for apparent reductions due to statistical error rather than 'real' savings. However, it is debatable as to whether the industry should be rewarded for carrying out repairs that should be done as a matter of course. It is Ofgem's responsibility to ensure the necessary investment in pipeline infrastructure is made and maintained in the long term. Direct legislation through, for example, mandatory standards for leakage, is required to secure further emissions reductions. Improved data would also help in monitoring and enforcing such targets.

Venting from rigs

Emissions trading has proved effective in encouraging methane capture from rigs. However, with the cessation of the UK ETS in 2006, the opportunity for trading methane will be lost, at least for two years until the EU ETS review. This results in a dilemma for the UK Government: to either legislate to encourage methane capture and underpin the savings already made or wait for two years until trading can recommence. Any legislation must ensure that methane reductions can still be classed as additional so as not to undermine the market for trading in the future.

Coal mine methane



8.1 Production

Coal mine methane (CMM) is the term given to the gas trapped in coal seams, which has an approximate chemical composition of 70% methane, 15% carbon dioxide and 15% nitrogen. The gas is released once the seams are mined and can then escape to the atmosphere.

Internationally, the UK was the sixth largest producer of coal mine methane in 1990,¹⁴⁰ behind China, the former Soviet Union, the USA, Germany and South Africa. The UK submission to the UNFCCC declares that 0.24 Mt of methane were

emitted from active coal mines during 2002, accounting for 12% of all UK methane emissions. Historically, the contribution of coal mine methane to the UK's methane budget was more significant when major coal fields in the UK where extensively mined for power generation and industry (Figure 20). However, the decline of the UK coal industry and subsequent large scale pit closures has resulted in far fewer mines and emissions. In 1947 there were 958 mines producing 189.6 Mt of coal annually. At present, there are just 17 deep mines and 39 open cast mines in the country, producing a total of 27.8 Mt coal in 2003.¹⁰⁵ The open cast mines release methane directly to the atmosphere. However, emissions from such mines are small as the seams lie close to the surface and have retained little of their original methane over geological time.⁷⁵

Why recover coal mine methane?

The primary reason for recovering coal mine methane is safety. Historically, underground mine explosions have been the cause of many injuries and fatalities, so reducing methane concentrations underground has aided mine safety operations.

Secondly, there is an economic motivation: if methane from coal mines can be captured, it can be used directly as a fuel or to generate electricity.

Lastly, there is the environmental imperative: reducing emissions of methane to the atmosphere aids the meeting of Kyoto and other targets.

Abandoned mines

In 1988, a house in the village of Arkwright in Derbyshire exploded due to contamination of the village with seeping coal mine methane. Because the ground above mined seams subsides and fissures slightly, methane can seep through the bedrock and find its way to the surface, often miles from the pit head. This incident was a key factor in alerting the industry and Government to



Figure 20: Coal fields in the UK

Source: Bibler, 1998¹⁴⁰

the environmental impacts of methane emissions from abandoned mines.

A major shortcoming of the UK UNFCCC submission is that it only includes emissions from active mines. At present, the decrease in methane emissions accounts for 30% of the UK greenhouse gas emissions reductions achieved since 1990, with coal mine closure responsible for 36% of this (i.e. 12% of total greenhouse gas emissions reductions). Inclusion of methane emissions from abandoned mines may significantly alter these figures. Both the current figures and the 1990 baseline would be higher and, whilst emissions from the sector would still decline over this period, it would not be so pronounced as currently implied.

A suitable methodology has not yet been developed for the inclusion of abandoned mines. This is a worldwide problem, but particularly pertinent in the UK. Whilst it is true that emissions from active coal mines are higher than from disused mines because the mining process opens up pockets of methane, abandoned coal mines are still capable of producing significant quantities of methane. This is especially true in the UK where 1096 coal mines have been abandoned since 1947,¹⁴¹ compared to the 17 deep mines still currently active.

Emissions of methane from abandoned coal mines are poorly quantified at present, with estimates ranging from 0.02 to 0.3 Mt per year.⁶⁴ The large range of values is an indicator of the massive uncertainty in these estimations. At the low end of this range, inclusion of abandoned coal mine methane makes a negligible contribution to UK methane emissions. The upper end of this estimate corresponds to more than doubling the methane released from coal mines and would make coal mines (active and abandoned) the second largest source of methane in the UK, responsible for 21% of UK methane emissions. The Association of Coal Mine Methane Operators (ACMMO) believes emissions from abandoned mines to be higher still, at 0.6 Mt per year, by including seepage from unvented mines

as well as those with vents.¹⁴² They estimate that 45 sites in the UK are commercially viable, capable of supporting 300 MW of electricity generating capacity and saving 0.37 Mt of methane.¹⁴²

However, the DTI maintain that coal mine methane from abandoned mines is not a problem in the UK and use this assumption as the basis for their policy recommendations. They estimate that just 0.05 Mt of methane are emitted from sites capable of being controlled.¹⁴³ Furthermore they assert that methane seepage from mines will rapidly diminish, particularly if flooding occurs.

The Association of Coal Mine Methane Operators claim that the DTI have seriously underestimated both the extent of the resource, the number of possible projects and overestimated the rate in decline of emissions.¹⁴⁴ The huge discrepancy in both the postulated resource and its longevity requires further independent research. At present, poor knowledge is likely to lead to inappropriate policy and economic support measures – particularly if the problem is not perceived as serious.

8.2 Mitigation

Non-extraction

The flow of methane from abandoned coal mines may be inhibited by blocking vents and sealing pathways where methane is detected. Alternatively, the coal mine may be flooded, providing an aqueous barrier to methane emissions.¹⁴³ Transport of methane through the water layer is prevented by its low solubility. Flooding can be an attractive option where there is no risk of aquifer contamination and where there is a suitable water resource available for the operation.

Such techniques are only applicable to sites where the risk of uncontrolled emissions is low. Because methane can seep along fissures and cracks in de-stressed bedrock many miles from its source, this is not seen as a workable option for most sites. Indeed, the Coal Authority has had to



Methane emissions from abandoned coal mines are not recognised by national inventories

install a further 40 vents at abandoned mines around the country since 1994 to cope with the hazards of new leakage points.¹⁴³

The preferred options of methane emission mitigation revolve around recovery and conversion to carbon dioxide.

Extraction

Coal mine methane can be extracted from mines in four different ways: through an existing gas vent, a vent well, a gob gas well and a CBM well.

Existing gas vent

All active coal mines have an existing gas vent to remove methane from the mine for safety reasons. Typically this gas is merely vented to the atmosphere, although some UK collieries do utilise the methane liberated. In active mines, ventilation air methane (VAM) is the major source of methane because the throughput of ventilation air is so high. Once the mine is no longer active, the VAM can still be drawn through the vent and captured, rather than being lost to the atmosphere (Figure 21).

Vent well

The upper layers of rock above a coal mine can often subside and fissure, creating a pathway for methane to seep through to the surface. This diffuse flow is difficult to capture and can result in significant methane emissions. A vent well can be drilled into the disused mine away from the central shaft and, by pumping on the well, methane will preferentially exit by this simpler route. Methane captured here also reduces methane emissions to the atmosphere.

Gob gas well

Gas trapped in distressed coal seams near the coal face (known as gob gas) will release methane into the mine or out through porous rock strata to the atmosphere. Drilling into this seam and pumping allows the gob gas to be captured. For abandoned mines this clearly reduces methane emissions, whereas for active mines, such a process mines the gas before the coal is extracted.

CBM well

Vents can also be drilled directly down into coal seams adjacent to the coal face. Virgin coal seams are stimulated and, after removing any water, methane can be extracted from the coal seam. This is essentially a direct mining process involving the creation of a virgin coal bed methane (CBM) mine. As such it is not mitigating against methane emissions as the methane present in the coal bed would not naturally have

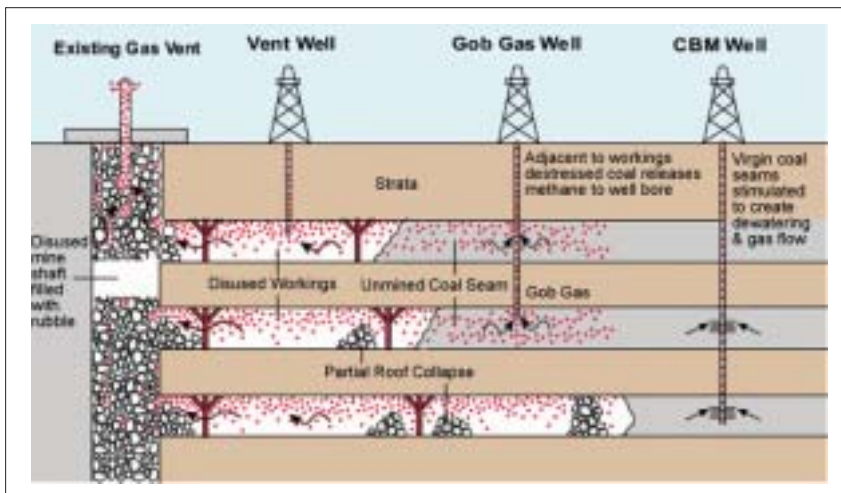


Figure 21: Recovery of methane from abandoned mines

Source: The Coal Authority, 2001¹⁴⁵

escaped to the atmosphere. CBM is a fossil fuel resource and therefore is not be eligible for ROCs.

Acceleration of coal mine methane

Pumping coal mine methane results in a more rapid removal of methane from the mine than would occur naturally and possibly increases the amount of methane extracted. This lowers the pressure inside the mine and increases the desorption of methane from the coal seams. However, there is still much debate within the scientific community about the extent of acceleration.³³

The extent of acceleration has implications for the trading of methane – does it matter that methane is being extracted from the mine faster than baseline natural emissions? Currently, it is believed that either accepting all extracted methane by ignoring the acceleration issue or

allocating a fraction of output to be eligible would both be feasible methods for emissions trading.³³

Using captured methane

Once captured, coal mine methane is either vented to the atmosphere, flared (oxidising the methane to carbon dioxide) or utilised in some form of energy recovery. The latter is the preferred environmental option but not necessarily the most economic since, as a non-renewable resource, the electricity does not qualify for ROCs. In 2003, 0.8 TWh of electricity was generated from colliery methane.¹⁰⁵ Methane is currently captured at seven operating sites and utilises a mixture of flares, generators and gas utilisation for boilers. Electricity is generated at six of these sites. Electricity generation from CMM also takes place at seven abandoned mines,¹⁴⁶ with a total capacity of 35 MW. ACMMO estimates that around 300 disused coal mines have the potential to generate electricity from CMM, which would result in an installed capacity of around 400 MW.¹⁴⁷

The purity of the methane extracted varies depending on its source. Gob gas is of medium quality, typically containing 30-90% methane, which is a sufficiently high concentration to utilise abatement technologies similar to those employed in landfill.

Ventilation air methane and vent well methane are of lower purity (less than 1% methane), but more sophisticated technologies now exist that are capable of utilising this gas directly.¹⁴⁸ Flow reversal reactors use a bed of silica gravel or ceramic as a heat exchange medium. The bed is preheated to 1000°C to initiate methane oxidation and the VAM is passed into the bed. As the methane combusts, the temperature rises and the excess heat can be recovered from the exhaust gas. This process also causes the far side of the bed to heat up, so the direction is reversed periodically to ensure that the combustion hotspot remains in the centre of the reactor bed (Figure 22).

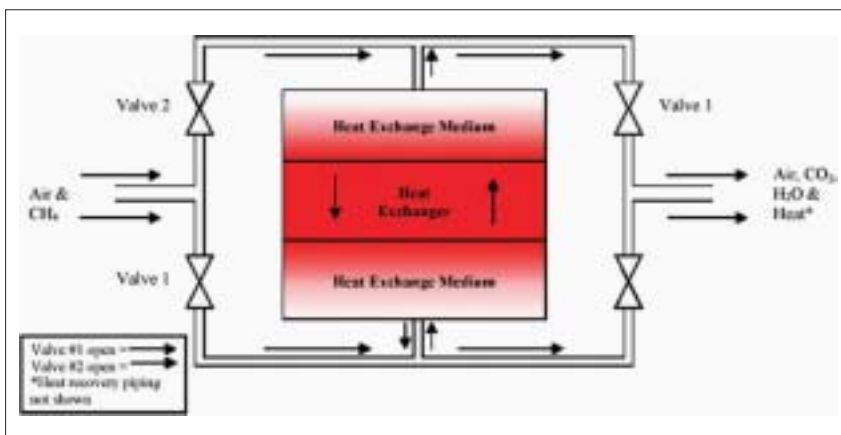


Figure 22: Thermal flow reversal reactor

Source: US EPA Coalbed Methane Outreach Program, 2003¹⁴⁹

Ventilation air methane may also be utilised as combustion air – in other words it is used as a ‘primed’ air mix for the combustion of other fuels. In this way, the calorific value of the VAM is not lost. Such a process requires an alternate source of fuel on site.

8.3 Current policy

Coal mine methane emissions

The UK’s current policy on coal mine methane has recently been laid out by the DTI.^{33, 143} The DTI assessed a total of 18 different policy instruments on the basis of cost effectiveness, ease of implementation and political acceptability. Environmental best-practice was not considered as one of the criteria. The most important factor in deciding which policy to utilise was the assumption that the methane resource from abandoned mines is small and will reduce over time through natural processes. However, as noted earlier, this is a highly contentious statement.

The favoured policy instrument was a series of competitive bidding rounds amongst Production Exploration and Development Licence (PEDL) holders across relevant sites for the most cost-effective bids to control methane emissions. The UK Coal Authority will be responsible for overseeing this process, thereby extending its environmental duties from mine water alone to include greenhouse gases. In most cases, given the lack of financial support for electricity generation, it is likely that simple flaring will be the most cost-effective choice. This policy will work alongside existing mechanisms, including the Climate Change Levy (CCL) and emissions trading.

Of the other policies considered, neither of the other two ‘front-runners’ – do nothing or incorporation into the Renewables Obligation – were deemed acceptable or consistent with current Government policy. Whilst ‘do nothing’ is the lowest cost option, it is inconsistent with Government environmental objectives and runs

contrary to the commitments made on coal mine methane within the Energy White Paper.⁸ Incorporation into the Renewables Obligation was rejected on the grounds that coal mine methane is not a renewable resource and that it would infringe EU rules on state aid. Development of an ‘Alternative Obligation’ for encouraging non-renewable, yet beneficial, low-carbon technologies was rejected for fear of raising the ‘nuclear question’.

Whilst the proposal for a competitive grant scheme is still at an early stage, it is clear that the emphasis is on control options, rather than electricity generation. Many proposed methane mining schemes are to be scrapped due to insufficient Government incentives.¹⁵⁰ Alkane, a major CMM company, has dropped proposals for 50 MW of electricity generating capacity in Ayrshire and is likely to take its operations abroad to Germany where economic conditions are more favourable.

Climate Change Levy

Since April 2002, electricity generated from coal mine plants has been exempt from the Climate Change Levy (CCL).¹⁵¹ This full exemption was incorporated in the 2002 Finance Act, which accorded CMM renewable status for the purposes of exempting it from the CCL.¹⁵² The Government claims that the exemption was granted on the basis that electricity generated from CMM offers both environmental gains and employment opportunities.¹⁵¹ This creates a policy inconsistency where coal mine methane is eligible for Levy Exemption Certificates (LECs) but not ROCs.

Exemption from the CCL was expected to boost electricity generation from CMM with a consequent reduction in GHG emissions. However, the price of LECs is low at approximately £4/MWh; an order of magnitude smaller than ROCs. As a stand-alone policy, the Climate Change Levy will not provide a sufficient economic driver for investment in electricity generation technologies.



Capture of coal mine methane results in both safety and environmental benefits

Emissions trading

In order for the industry to continue to reduce emissions throughout the UK, the Government has offered support through other policies such as the UK Emissions Trading Scheme (UK ETS). Under the UK ETS, coal mine methane has been incorporated and rewarded for its environmental benefits through trading by UK Coal. However, trading is only allowed for emissions credits generated from active mines (either through flaring or electricity generation). Emissions from abandoned mines do not qualify for carbon credits since there is no baseline measure for these emissions and therefore no way for reductions to count.

DEFRA has commissioned studies to determine a baseline for abandoned CMM emissions that could enable it to qualify for this scheme,^{64, 141} although so far only a protocol for methane from working coal mines has been developed.¹⁵³

8.4 Recommendations

The key factor in determining the importance of this sector lies in the debate around abandoned coal mines, which could shift the current policy focus. In terms of capturing CMM from both active and abandoned mines, the technology is available and ultimately it depends on the policy emphasis as to how the captured gas is then dealt with.

Abandoned coal mines

At present, only methane from active mines is recognised by international targets. As a consequence, emissions from abandoned mines are not given the same policy priority as methane emissions that actively help the UK achieve these targets. It could be that emissions from abandoned mines represent both a significant problem and resource in the UK, but there is a great deal of uncertainty surrounding current estimates. Not only does this represent a major environmental issue, in terms of possible methane emissions which are currently unchecked, it is also a potential missed



Over 27 Mt of coal was produced in the UK in 2003

opportunity – an unexploited resource which could provide both financial and environmental benefits as well as employment opportunities.

An essential first step in addressing this issue would be to quantify these emissions accurately. This would involve developing an internationally agreed methodology for estimating emissions from abandoned mines, which currently does not exist. These emissions could then be included in the UK inventory for the UNFCCC. This would affect both current and historic estimates of emissions and therefore the contribution towards the Kyoto target. Improved data quality would provide a firmer foundation on which to build policy and may require a change in policy direction. The development of a reliable baseline for abandoned mines would also be required to enable trading of these emissions. Until estimates are improved, the debate and conjecture will persist and methane will continue to be released into the atmosphere.

Policy

Methane capture

Current policy addresses capture at active sites but not from abandoned mines. Until emissions from abandoned mines are better quantified, there is unlikely to be any change in this situation.

Electricity generation

Following the recent DTI review, the emphasis in current policy is on control, most likely in the form of flaring, rather than energy recovery. Whilst this is successful in reducing methane emissions and usually the most cost-effective option, it does not maximise the environmental benefits of capturing the gas. Because methane from both active and abandoned mines is a non-renewable resource, the economic incentives are not in place to encourage the implementation of best-practice technologies. Apart from the Climate Change Levy, there are no other policies or incentives for

energy recovery and the Levy Exemption Certificates do not have a high enough market value to encourage energy generation. Fiscal policies such as trading will encourage flaring rather than electricity generation, as the most cost-effective option. Other policies such as feed-in-tariffs (as in Germany) and incorporation into the Renewables Obligation have been rejected by the DTI as inconsistent with existing Government policy.

Given the lack of financial incentives, if electricity generation is to be encouraged it will require some support from the Government. This could be in the form of grants or subsidies to encourage the implementation of best-practice technology, or through legislation, similar to the EU Landfill Directive. This could have implications for trading since emissions reductions required or supported in this way may not then be eligible to trade.

New technology

There is still room for improvement in current methane capturing technology, but investment in increasing efficiency is likely to require some form of incentive. Similar to energy recovery technologies, if there are no strong financial incentives to encourage improved capture, support may be needed through grants and subsidies or legislation.

Methane trading

The successful trading of methane from active coal mines on the UK Emissions Trading Scheme demonstrates the feasibility of this approach for this sector. Inclusion of emissions from abandoned mines could potentially double the size of this market, but first requires the establishment of a reliable baseline. The two year gap between the closing of UK ETS and entry of methane into the EU ETS provides a timely opportunity to establish this baseline and investigate the potential of this market. As in the oil and gas sector, with this gap in trading, the UK Government faces a choice between legislating to

underpin the savings made to date or putting the process on hold for two years until trading can recommence. Similarly, any mandatory requirements will impact on the viability of the future trading market.

The current political situation in the UK means that whilst trading will aid the economics of installing capturing capacity it will only encourage capture and flaring rather than electricity generation. Other policy measures need to be put in place to promote the adoption of energy recovery, which could then be supported through trading.

Discussion and conclusions



9.1 Importance of methane

Methane is a powerful greenhouse gas, twenty-three times more potent than carbon dioxide (over a 100 year lifetime) and with a relatively short atmospheric lifetime of just 12 years, meaning that emissions reductions are rapidly translated into atmospheric concentration reductions. Therefore mitigating methane is highly cost-effective, particularly in the short term. Despite this, there is currently a lack of policy specifically targeted at methane.

There is also a climate change imperative for reductions in methane emissions to be achieved sooner rather than later – the higher the concentration of methane in the atmosphere, the more slowly it is removed by natural processes due to feedback loops in the atmospheric chemistry of the gas. Therefore it is more effective to reduce emissions in the short term; failure to do so will increase the lifetime of methane in the atmosphere and make it an even more potent greenhouse gas.

Controlled properly, methane represents a valuable resource – it is a combustible fuel with a high calorific value. Once captured, combustion of methane produces the less potent carbon dioxide and energy, which can then be used for heating or electricity generation. Production of electricity from methane will offset electricity production from the more polluting national energy mix.

Hence, the chemistry and physical properties of methane make it an attractive option for emissions reductions within the framework of the basket of six greenhouse gases, providing both environmental and economic benefits. The question is how best to secure these reductions – what policies and technologies would be most effective?

9.2 Disparity of methane sources

This report has focused on the four major sources of methane in the UK: landfill, agriculture, gas pipes and coal mines. These are disparate in

nature, differing in the way in which the methane is generated, control options available and the overall policy context.

Sources may be either biogenic (agriculture, landfill) or fossil fuel derived (gas leakage and coal mines). This has implications for how methane is classified (renewable or non-renewable) and therefore its eligibility for financial rewards such as ROCs. Furthermore, the source may be a single point and therefore inherently capturable (landfill, coal mines) or essentially diffuse (agriculture, gas leakage). To a certain extent, this determines whether the policy emphasis is on capture or reduction and whether the resource can be further exploited.

Each sector also has its own political history, with different players and sensitivities, and particular policy focus. All these factors together make identifying a single unifying methane policy a major challenge.

9.3 Methane trading

Although there are policies in place that will have the effect of reducing methane, these are not uniform across the four major sectors and are often focused on a different goal (e.g. diverting waste from landfill). Methane trading was a key option considered in this report as a possible means of unifying policy into a single coherent abatement mechanism. According to the main criteria necessary for an effective emissions trading scheme (Chapter 3), there are a number of drawbacks to implementing a UK methane trading scheme:

- *Commodity to trade.* This requires quantification of the methane available for trading which is most easily achieved through capture, but this is only possible in certain sectors.
- *A liquid market.* The methane market alone is too small to function efficiently since the volumes involved are too low. For methane to be traded it must be incorporated into a multi-gas trading scheme.

- *Suitable mix of players.* There is a wide variation in the size of players across the different sectors, from big oil companies to individual farmers, with a large number of small players, which would result in an inefficient market.
- *Additionality.* Mandatory requirements for methane reductions are already in place in several sectors so future reductions could not be considered additional and are therefore not tradable.
- *Monitoring, reporting and verification.* In the sectors where methane is capturable (landfill and coal mines) data quality is poor with no reliable baseline to provide certainty and allow for verification.
- *Conflicting policies.* Where methane is captured and used to generate electricity, it is financially advantageous to accrue alternative environmental rewards such as ROCs due to their high market value, rather than carbon credits. Since the savings cannot be counted twice, this undermines any potential trading market.

It is apparent that a separate methane market does not represent a viable option for the UK, nor would methane trading work as the sole approach to cover all sectors. However, trading methane certainly has potential for some sectors, as demonstrated by the successful trading in the

UK Emissions Trading Scheme (UK ETS) by the coal and gas industry.

The possibilities for trading vary between sectors, as detailed below and summarised in Table 16.

- *Landfill.* Methane is capturable, but does not count as additional since capture is already required for safety reasons and also covered at new sites by the Landfill Directive. A reliable baseline is difficult to define, partly due to the lack of data on landfill sites and partly due to the change in levels of methane emissions that occurs naturally over time. Any electricity generated from the captured methane will be eligible for ROCs, removing the incentive to trade.
- *Agriculture – livestock.* Livestock emissions are diffuse, with no easy means of capture and no accurate method for estimating a baseline. As small players, individual farmers would find it hard to compete effectively in a trading scheme – some form of aggregation would be necessary but this would introduce further complexity.
- *Agriculture – manure.* With appropriate management, emissions from manure are capturable, although there is little data currently available to determine a baseline of emissions. The methane captured would be additional since there are no other policies in this area, but the availability of ROCs may undermine the potential for trading.

Table 16: Potential for methane trading in each sector

	<i>Is methane capturable & quantifiable?</i>	<i>Reliable baseline?</i>	<i>Is methane additional?</i>	<i>Policy conflict?</i>	<i>Trading?</i>
Landfill	Yes	No	No	ROCs	No
Agriculture					
– livestock	No	No	Yes	No	No
– manure	Yes	No	Yes	ROCs	Possible
Oil & gas rigs	Yes	Yes	Yes	No	Yes
Gas pipeline	No	No	Some	No	Possible
Coal mines	Yes	No	Yes	No	Yes



Methane trading is unlikely to be an option for reducing livestock emissions

- *Oil & gas rigs.* Methane is capturable, additional and quantifiable with no policy conflicts, resulting in a high trading potential.
- *Gas pipelines.* In a sense, emissions from pipeline leaks are (re)captured by repairing the leak, since the methane is already captured within the pipe, but these emissions reductions are not easily quantified. For trading to be possible, a reliable baseline, through improved monitoring, needs to be established to enable quantification. Only those emissions not covered by Health and Safety legislation would count as additional.
- *Coal mines.* Trading potential for this sector is high, capture of emissions being reasonably straightforward and additional, with no policy conflicts. Methane from active mines has been successfully traded. However, there is huge uncertainty regarding emissions from abandoned mines, which could double the market size. Better quantification is required before any trading of these emissions can commence.

Given the forthcoming closure of the UK ETS in 2006, the future of methane trading is somewhat uncertain, awaiting the review of the EU ETS in 2006. It is essential that methane is incorporated into the European scheme in 2008, given its importance as a greenhouse gas. Even limited trading should be encouraged because of the potency of the gas. In addition, some consideration needs to be given to the two year gap following the end of the UK ETS in 2006. The UK Government is faced with a choice of putting the process of methane reductions from trading on hold for this period or underpinning the savings achieved to date through legislation. Any policies must ensure that the methane reductions can still be classed as additional to allow trading of these emissions in the future.

Although the opportunities for methane trading in the UK are limited, mainly due to the presence of ROCs, there may be greater scope for trading in other countries. Under the EU ETS, the

Joint Implementation and Clean Development Mechanism of the Kyoto Protocol open up the possibility of trading reductions secured through projects in other countries, which could help boost the market in the UK.

Despite the fact that methane trading does not represent the ultimate solution in terms of single coherent approach for reducing methane emissions, it still has a role to play as part of a synergistic policy package. However, the future of the market is dependent on inclusion in the EU ETS. Until this is certain, the potential of this policy option will be left hanging.

9.4 Recommendations

Based on the likely future emissions from each sector and the effect of planned policies and measures, annual methane emissions are expected to decrease by 16.5% by 2020.¹³⁶ However, additional policy measures have the potential to reduce this yet further, with a suite of policies to address the different requirements in each sector; these are illustrated in Table 17 and discussed on a sector by sector basis below.

Landfill

Reductions in methane emissions from landfill sites can be achieved by two routes: capturing any methane produced as a result of anaerobic decomposition of biodegradable waste and reducing the amount of biodegradable waste sent to landfill in the first place, as laid out in the EU Landfill Directive.

One of the key issues for this sector is data quality. There is uncertainty about the exact number of landfill sites in the UK and extent of capture at many of these sites, particularly older and closed sites. It could be that a significant source of methane emissions is being overlooked. A detailed inventory of all landfill sites is essential, providing information on the capture technologies employed at each site to give an indication of where further reductions could be made.

Table 17: Disparity of methane sources and appropriate mitigation measures

	<i>Collectable</i>	<i>Non-collectable</i>	<i>Possible measures</i>
Biogenic	Landfill Agricultural manure management	Agriculture livestock	Divert from landfill Societal trends
Fossil fuel	Coal mine methane	Gas pipe leakage	Carbon trading Direct policy measures
Possible measures	Flare Revenue streams: – use as heating fuel – generate electricity – ROCs or carbon trading	Reduce at source Carbon trading (if quantifiable) Direct policy measures	

In modern landfills, 85% of the methane can be captured²⁵ although the capture rate could be increased still further. Older landfill sites with less advanced capping technology have lower rates of capture. If such sites are found to be a significant source of emissions, investment will be needed to find solutions to improve capture at these sites. The prime economic policy instrument for improved methane capture at present is eligibility for ROCs through the generation of electricity from landfill gas.

The success, or otherwise, of the Landfill Directive will depend on effective alternative methods for the disposal of biodegradable waste. Whilst there is no lack of such options – composting, recycling, incineration – the main obstacle appears to be their implementation. An increase in composting or recycling requires individuals to change their waste disposal habits and, although composting and recycling rates have increased, it is unclear whether these are capable of increasing to the levels required by the Directive. Incineration is also unpopular amongst the UK public, with health concerns about dioxins and other emissions from waste incineration plants. Furthermore, electricity generation from incineration of waste does not qualify for ROCs.

Anaerobic digesters offer the best alternative at present, particularly as part of a mechanical

biological separation scheme, with close to 100% methane capture and no atmospheric emissions. The gate fees for accepting the waste are a key economic driver for this technology. In addition, electricity generated from the methane is eligible for the strong financial rewards of ROCs. However, in order to encourage the initial uptake of this technology, it may be necessary to provide additional support in the form of grants and subsidies, since it is a relatively unproven technology in the UK.

The effectiveness of the Landfill Directive in achieving significant reductions in landfill methane emissions remains to be seen. There is some incompatibility with the UK Renewables Obligation, since a reduction in biodegradable waste going to landfill will reduce the profitability of methane capture and could theoretically make capture and use unviable. However, substantial amounts of methane will be produced from the biodegradable waste already present in landfill for many years to come, minimising any potential conflict.

Agriculture

The agricultural sector is the largest source of methane within the UK, but the hardest one in which to achieve emissions reductions, reflected in the lack of policies that target this source.



Strong regulation is required to reduce leakage from gas pipes

Livestock emissions

Some 90% of emissions are from ruminant mammals such as cows and sheep. These sources of methane are a multitude of mobile point sources rendering capture of the methane unfeasible. Reduction of methane at source is therefore the only sensible mitigation measure. However, the policy options available to achieve this are fraught with difficulty. Enforcing a reduction in livestock numbers would alienate the farming community whereas increasing productivity or reducing emissions per animal through dietary adjustments or genetic engineering is likely to be unpopular amongst the public.

Some decrease in the number of animals may occur as a result of reforms to the EU Common Agricultural Policy (CAP). The current societal trends towards organic produce and vegetarianism may also help reduce livestock numbers, but not by any significant amounts and this is also an area that would be difficult to legislate. Supporting moves towards more sustainable methods of farming could be of benefit over the longer term by reducing livestock densities.

It seems that it may be necessary to accept a certain level of methane emissions from

agriculture if the UK is to retain a livestock farming industry.

Manure management

Options for reducing methane emissions from animal manure are more straightforward, the most favourable being the use of anaerobic digesters. A strong economic driver is already available through eligibility for ROCs. The main focus here needs to be on raising awareness about this technology amongst the farming community and encouraging its uptake through grants and subsidies and the formation of farming co-operatives with shared digester facilities.

Oil and gas industry

Natural gas leakage

Once again, poor data quality is a key issue for this sector. At present, estimates of methane emissions from pipeline leaks are very poorly quantified, with errors of $\pm 40\%$. This represents one of the main barriers to trading at present, with a risk of trading apparent reductions due to statistical error rather than 'real' savings. Improved monitoring and data collection are required to establish the extent of this problem.

Due to the relatively low price of gas, there is little economic incentive to repair leaks and reduce emissions. Programmes such as the USA's Natural Gas STAR programme help to reduce emissions through market-based activities that benefit both the industry and the environment. However, stronger measures are needed to achieve significant reductions, with Ofgem overseeing tighter regulation on pipeline leakage and the setting of mandatory standards. Any such legislation would remove the possibility of trading from this sector, but it is questionable as to whether the industry should be rewarded for carrying out necessary repairs anyway.

Venting from rigs

Reducing methane emitted as a result of rig flushing is straightforward through flaring or

sequestration of the captured methane. The primary economic incentive for achieving these reductions to date has been through the trading of methane on the UK ETS. This raises the question of what will happen once the UK ETS is closed. Clearly, it is not desirable to have technologies ready to be implemented in the UK, yet no policy or financial drivers to encourage this until methane can be traded on the EU ETS in 2008. An interim policy measure is required to reward any greenhouse gas emission abatement that occurs in the period to 2008. However, if trading of these emissions is to continue in the future, any measures must ensure that the methane reductions can still be classed as additional.

Coal mine methane

A major issue for this sector is emissions from abandoned mines. Estimates of these emissions vary by a factor of 10 and so could represent a significant, but unrecognised, source of methane emitting to the atmosphere. Reliable inventory information and international agreement on how to classify methane from abandoned coal mines are a priority to put this source into perspective and assist in future policy decisions on its status.

Once a source is identified, coal mine methane is straightforward to capture and therefore easily quantified, making it an ideal candidate for trading, as demonstrated by successful trading in the UK ETS. Methane from both active and abandoned mines should be traded. The value of carbon credits should provide a sufficient driver for investment in the capital equipment required to capture the coal mine methane. Without ROCs, there is currently little incentive to use the captured methane to generate electricity since flaring is the cheapest option and all that is required for trading (the trading value determined by offsetting the methane saved against the carbon dioxide produced). Flaring is also the method favoured by present policy, which focuses on the most cost-effective control of emissions from active mines. Environmentally,

energy recovery is the preferred choice, but this requires more active support from the Government.

As with emissions from oil and gas rigs, once the UK ETS has closed, it is recommended that interim support policies are introduced to support emissions reductions until methane trading is incorporated into the EU ETS. Once again, these measures must ensure that any methane reductions can still be classed as additional if trading is to occur in the future.

9.5 Conclusions

Reductions in methane emissions represent a rapid and cost-effective option for lowering greenhouse gas emissions. It is essential that these reductions are realised now, before atmospheric concentrations of methane rise and its potency increases.

Although methane trading is at first sight a highly attractive option for mitigating methane emissions, in practice most methane generating sectors are excluded due to other policy instruments (no additionality), other economic drivers (more attractive), small players (reduces liquidity) and poor quantification of emissions (introduction of hot air). Only coal mine methane and emissions from oil and gas rigs are currently viable sectors for exploiting the methane trading opportunity and this is dependent on incorporation into the European Emissions Trading Scheme in 2008.

A synergistic package of policies is required in each sector to secure the significant potential reductions and in nearly all cases improved data collection is necessary. Technological development and social and economic policy all have an integrated role to play. Methane abatement has been overlooked in the past, but it is a crucial component in mitigating climate change and should be an early focus of any strategy to reduce greenhouse gas emissions.

Glossary

<i>Abandoned coal mines</i>	Mines which are no longer being mined for coal
<i>Abatement</i>	A reduction in the amount or intensity of emissions
<i>Active coal mines</i>	Mines which are still operative and producing coal, either deep mines or open cast
<i>Additionality</i>	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
<i>Aerobic</i>	In the presence of, or requiring, oxygen
<i>Allowances</i>	The right to emit a quantity of a pollutant under an emissions trading scheme
<i>Anaerobic</i>	In the absence of oxygen
<i>Anthropogenic</i>	Made by humans or resulting from human activity
<i>Baseline-and-credit system</i>	A market-based approach which allocates a pre-determined emissions profile to each participant and allows trade in the unused portion of that profile
<i>Bedrock</i>	The solid rock that underlies soil and other loose material
<i>Biodegradable</i>	Material that can be broken down by micro-organisms into simpler compounds
<i>Biogas</i>	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
<i>Biogasification</i>	The breakdown of complex biological materials by anaerobic bacteria to more useful forms of fuel: carbon dioxide and methane
<i>Biogenic</i>	Produced by the action of living organisms or biological processes
<i>Biomass</i>	Plant-based materials that can be burned to produce energy or converted into a gas and used for fuel
<i>BSE</i>	Bovine Spongiform Encephalopathy is a chronic progressive degenerative disease affecting the central nervous system of adult cattle, also known as Mad Cow Disease
<i>Calorific value</i>	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
<i>Cap-and-trade system</i>	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
<i>Capping layer</i>	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

<i>Carbon credits</i>	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
<i>Carbon cycle</i>	The exchange of carbon in various forms (carbon dioxide, carbonates, organic compounds <i>etc.</i>) between the atmosphere, ocean, terrestrial biosphere and geological deposits
<i>CDM</i>	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
<i>Clear Skies Programme</i>	UK capital grant scheme for promoting renewable energy technologies including solar thermal, biomass boilers and heat pumps
<i>Climate change</i>	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"
<i>Co-firing</i>	The use of two or more different fuels (<i>e.g.</i> wood and coal) simultaneously in the combustion chamber of a power plant
<i>Composting</i>	Biological decomposition of organic materials in the presence of oxygen by bacteria, fungi and other organisms into a soil-like product called humus
<i>Condensate</i>	A light liquid hydrocarbon produced when hydrocarbon vapours are cooled
<i>Digesta</i>	Intestinal contents
<i>Digestate</i>	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
<i>Dioxins</i>	Highly toxic compounds that are a by-product of incineration of plastics. Also generated by bush fires, volcanoes and vehicle emissions
<i>Direct emissions</i>	Greenhouse gas emissions by an entity from sources owned or controlled by that entity
<i>Energy recovery</i>	The process of extracting useful energy from waste, typically electricity or heat (or both)
<i>Enhanced greenhouse effect</i>	The increase in the natural greenhouse effect through increased concentrations of greenhouse gases as a result of human activities
<i>Enteric fermentation</i>	A digestive process of some mammals by which carbohydrates are broken down by micro-organisms into simple molecules to aid absorption into the bloodstream

<i>Eutrophication</i>	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
<i>Feed-in tariffs</i>	A form of support for electricity generated from renewable sources. Typically a premium price is paid to generators of green electricity
<i>Financial derivatives</i>	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
<i>Flange</i>	A device to connect a pipe to another pipe, a valve or other piece of equipment, and maintain a seal
<i>Foot and Mouth disease</i>	An acute contagious viral disease of cloven-footed animals (<i>e.g.</i> cattle, sheep, goats, pigs) marked by ulcers in the mouth and around the hoofs
<i>Fossil fuel</i>	Naturally occurring carbon or hydrocarbon fuel (<i>e.g.</i> coal, natural gas and oil) formed by the decomposition of ancient animal and plant remains formed over millions of years
<i>Gate fee</i>	The fee, usually quoted in £ per tonne, for processing waste at a treatment and/or disposal facility
<i>Global warming</i>	The rise in temperature of the earth's surface due to the enhanced greenhouse effect
<i>Global Warming Potential</i>	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)
<i>Grandfathering</i>	A method of centrally allocating emissions allowances, usually based on historical emissions
<i>Greenhouse effect</i>	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
<i>Greenhouse gas</i>	An atmospheric gas that has the ability to absorb infrared radiation, contributing to the greenhouse effect (<i>e.g.</i> water vapour, carbon dioxide, methane)
<i>Heat exchange</i>	The transfer of energy between two substances at different temperatures, providing required heating or cooling
<i>Heavy metals</i>	Metallic elements with high atomic weights that can damage living things at low concentrations and tend to accumulate in the food chain (<i>e.g.</i> mercury, chromium, cadmium, arsenic, and lead)
<i>Hot air</i>	Emissions reductions against a target that occur without any dedicated abatement actions (<i>e.g.</i> due to economic downturn or prior legislation)

<i>Hydrolysis</i>	Reaction of a chemical compound with water
<i>Hydroxyl radical</i>	A highly reactive molecule containing one oxygen and one hydrogen atom responsible for the removal of many trace pollutants from the atmosphere
<i>Indirect emissions</i>	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
<i>JI</i>	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)
<i>Leachate</i>	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
<i>Lifetime</i>	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
<i>Liquid market</i>	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
<i>Liquidity</i>	The ease with which an asset can be converted to cash
<i>Methanogenesis</i>	The production of methane and carbon dioxide by biological processes carried out by single-celled micro-organisms called methanogens
<i>Methanogenic</i>	Methanogenic micro-organisms produce methane and carbon dioxide by the fermentation of simple organic compounds or the oxidation of hydrogen under anaerobic conditions
<i>Methanotroph</i>	An aerobic bacterium with the ability to utilise methane as sole carbon and energy source
<i>Mitigation</i>	Steps taken to avoid or minimise a negative environmental impact. This might include minimising, rectifying, reducing or compensating for the impact
<i>Montreal Protocol</i>	An international agreement to limit further damage to the ozone layer by drastically reducing the production and consumption of ozone-depleting substances (<i>e.g.</i> chlorofluorocarbons, halons, carbon tetrachloride). The treaty was signed in 1987 and substantially amended in 1990
<i>Natural Gas STAR Programme</i>	A USA voluntary initiative which aims to encourage natural gas companies to adopt 'best management practices' that can profitably reduce emissions of methane
<i>Perturbation lifetime</i>	A measure of the lifetime of a gas that includes its influence on other atmospheric species that occurs during its physical lifetime.

<i>Potency (of a greenhouse gas)</i>	The capacity of a gas to absorb and radiate heat energy over a specified period of time
<i>Radiative forcing</i>	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
<i>Recycling</i>	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
<i>Renewable energy</i>	Energy obtained from sources which are essentially inexhaustible. Renewable sources include hydroelectric power, wood (biomass), geothermal, wind, photovoltaic and some waste
<i>Ruminant</i>	An animal that chews its cud, has even-toed hooves and a multi-chambered stomach (<i>e.g.</i> cattle, sheep, goats, deer)
<i>Termite</i>	A soft-bodied ant-like insect which feeds on wood
<i>Volatile organic compounds</i>	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
<i>Wetlands</i>	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

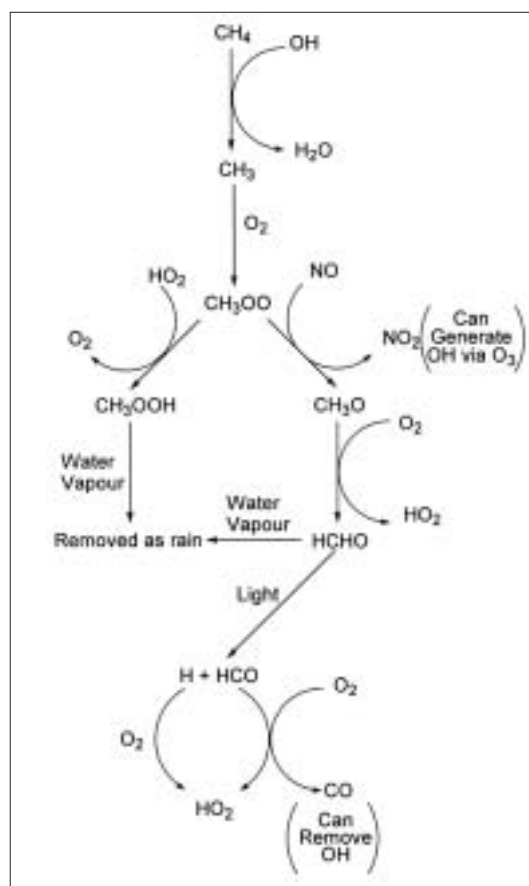


Figure 23: Oxidation of methane in the troposphere

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

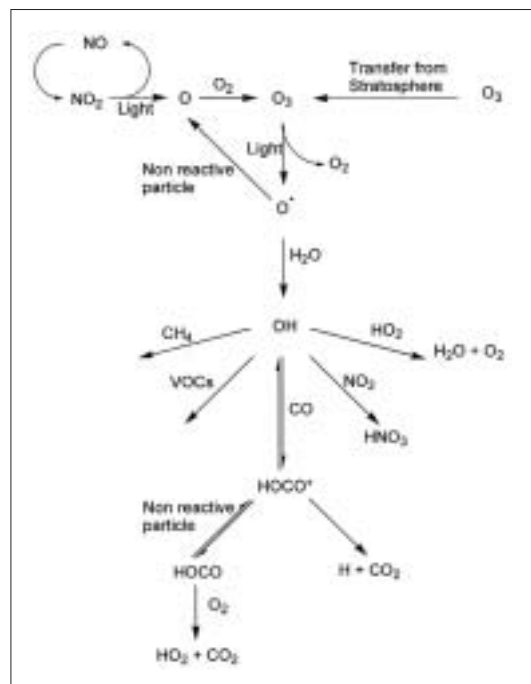


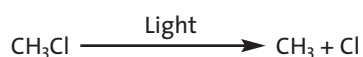
Figure 24: Sources and sinks of the hydroxyl radical

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.

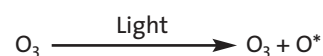
In the upper stratosphere, methane decomposition can be initiated in two other ways; by reaction with chlorine radicals or excited oxygen atoms. Ultraviolet light, which has high intensities in the stratosphere, causes the dissociation of a carbon chlorine bond, releasing a chlorine radical.



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



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



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



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 CH₄ 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 CH₄.

‘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 CH₄ from the atmosphere and is not included in the value of 30 Mt CH₄ taken up by soils annually. However, because methanotrophic bacteria working under low affinity oxidation conditions absorb up to 90% of the CH₄ produced by methanogenic bacteria in the same environment, they significantly reduce CH₄ 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 CH₄ 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 CH₄ concentrations may inhibit the microbial uptake of CH₄ 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 CH₄ by soils is only 30 Mt/yr.

Notes

Notes

Notes

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