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**THE POTENTIAL FOR USING TAX INSTRUMENTS TO ADDRESS NON  
CO<sub>2</sub> GREENHOUSE GASES: CH<sub>4</sub>, N<sub>2</sub>O, HFCs, PFCs and SF<sub>6</sub>**

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## FOREWORD

The Committee on Fiscal Affairs and the Environment Policy Committee launched a series of Joint Meetings of Tax and Environment Experts in 1999. One part of the mandate of these meetings was to monitor developments and contribute, where appropriate, to tax aspects of the follow-up to the Kyoto Protocol to the United Nations Framework Convention on Climate Change. As a contribution to this work, it was decided to undertake a study of the potential for using tax instruments to address non-CO<sub>2</sub> greenhouse gases, namely CH<sub>4</sub>, N<sub>2</sub>O, HFCs, PFCs and SF<sub>6</sub>. This study will serve as an input to the final report of the Joint Meetings, which is to be published in 2001.

It should be underlined that the purpose of the present report is to review the technical possibilities for levying taxes on the gases in question. The broader fiscal, economic and legal issues are not discussed.

This report was prepared by Ms. Fiona Mullins and Ms Jessica Troni of Environmental Resources Management in the United Kingdom. It is published under the responsibility of the Secretary-General of the OECD.

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## EXECUTIVE SUMMARY

### Introduction

Carbon dioxide is responsible for over 60% of the human contribution to the greenhouse effect (6 gigatonnes of carbon per year). Methane currently contributes 15–20% of the effect and nitrous oxide and other gases contribute the remaining 20 percent of the greenhouse effect. <sup>(1)</sup> In OECD countries, the share of CO<sub>2</sub> emissions is about 80%, while CH<sub>4</sub> represents about 10%, N<sub>2</sub>O about 7% and other gases about 2% of total emissions.

The definition of OECD countries obligations under the Kyoto Protocol as a basket of six gases has raised the profile of non CO<sub>2</sub> greenhouse gases. Emissions of these gases come from many different sources, each of which presents different challenges when considering taxation and other mitigation options. This paper documents the nature and sources of each gas in order to examine the possibilities for taxing them. The paper draws on the most recent available information but does not contain new research on these gases.

The feasibility of taxing non CO<sub>2</sub> gases depends largely on:

- how complicated it is to estimate or measure the emissions;
- the number of taxable events;
- the importance of each emission source in terms of current and expected future emissions; and
- other policies and measures that may be in place to address the emissions.

### Greenhouse Gas Sources that are Amenable to Taxation

The most important sources of each of the non CO<sub>2</sub> greenhouse gases in terms of quantities emitted are:

- methane (CH<sub>4</sub>) from landfills, enteric fermentation in ruminants, natural gas and oil systems, and coal mining;
- nitrous oxide (N<sub>2</sub>O) from fertilisers and industrial processes;
- hydrofluorocarbons (HFCs) used in place of ozone depleting substances (ODS) and HFC-23 as a by-product from production of HCFC-22;
- perfluorocarbons (PFCs) from anode effects during aluminium production; and
- sulphur hexafluoride (SF<sub>6</sub>) used in electrical insulators and during magnesium production.

Of these major emission sources, the most obvious possible candidates for taxation are CH<sub>4</sub> from modern landfills, CH<sub>4</sub> emissions from natural gas and oil production, N<sub>2</sub>O from use of fertilisers (with the tax placed at point of production or sale), production or sales of HFCs (and some PFCs) that are used as ODS replacements, and SF<sub>6</sub> used during magnesium production.

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1. UNFCCC website: <http://www.unfccc.de>.

*Table 1* below summarises the greenhouse gas sources that appear to be most amenable to taxation based on the broad analysis in this paper. The table includes all of the greenhouse gas sources that we consider warrant consideration for taxation based on the broad analysis in this report. The sources in the table with poor data quality or high levels of uncertainty are less well suited to taxation but may still warrant further consideration.

**Table 1. Greenhouse gas sources that are amenable to taxation**

Activity	Quantity of taxable entities	Importance	Ease of measurement/ monitoring	Emissions projection from 1995 to 2000 (per cent)
CH <sub>4</sub> from oil and natural gas production	Few (producers)	High	Reasonable	+3
CH <sub>4</sub> from modern landfills	Many	High	Good	-8
CH <sub>4</sub> from underground coal mines	Medium	High	Good (for underground mining)	-9
N <sub>2</sub> O from fertilisers	Many (purchasers)	High	Poor	+3
HFCs and PFCs used as ODS substitutes	Many (producers or purchasers)	Low but increasing rapidly	Good (complex to get complete accuracy)	+132
HFCs, PFCs, SF <sub>6</sub> emissions during production of these chemicals	Few	High	Good	
SF <sub>6</sub> used in magnesium processes	Few to medium	Low	Good	+19
HFC-23	Few	Medium (being phased out)	Good	-5
N <sub>2</sub> O from adipic acid	Few	High (but reducing)	Good	-58 (adipic and nitric)
N <sub>2</sub> O from nitric acid	Few	High	Good (but site specific)	“
PFCS from aluminium production	Low	Medium	Good (but site specific)	13

*Source:* reproduced from Tables 2.1, 3.2, and 4.6.

### Greenhouse Gas Sources that are Least Suited to Taxation

There are many sources of greenhouse gases that do not appear to be well-suited to taxation from the analysis in this report. These are summarised in *Table 2* below and described in greater detail in the text and in the conclusions. Measurement or estimation difficulties are the main reason behind proposing the sources in *Table 2* as least amenable to taxation.

**Table 2. Greenhouse Gas Sources that are Least Amenable to Taxation**

Activity	Quantity of taxable entities	Importance	Ease of measurement/ monitoring	Emissions projection from 1995 to 2000 (per cent)
CH <sub>4</sub> and N <sub>2</sub> O from vehicle fuel combustion	Many	Low	Poor	-0.1
CH <sub>4</sub> and N <sub>2</sub> O from stationary fuel combustion	Many	Reasonable	Poor	13.5
CH <sub>4</sub> from many existing landfills	Many	High	Poor	-8
CH <sub>4</sub> from surface coal mining	Medium	High	Poor (for open cast)	-9
CH <sub>4</sub> from natural gas distribution	Medium	Medium	Poor	+3
CH <sub>4</sub> from enteric fermentation	Many : farmers	Very high	Poor	+1.6
CH <sub>4</sub> from livestock production	Many: farmers	Medium	Poor	+5.5
CH <sub>4</sub> from waste water	Many	Low	Poor	+0.7
N O from spread of animal waste	Many	Low	Poor	+4
CH <sub>4</sub> and N <sub>2</sub> O from manure management	Many	Low	Poor	+2.5
HFCs, PFCs, and SF <sub>6</sub> used in the semi- conductor industry	Many	High	Uncertain	+71

Source: reproduced from Tables 2.1, 3.2, and 4.6

## 1. INTRODUCTION

### 1.1 Objective

Six greenhouse gases are included in developed country commitments in the Kyoto Protocol to the United Nations Framework Convention of Climate Change (UNFCCC): carbon dioxide (CO<sub>2</sub>); methane (CH<sub>4</sub>); nitrous oxide (N<sub>2</sub>O); hydrofluorocarbons (HFCs); perfluorocarbons (PFCs); and sulphur hexafluoride (SF<sub>6</sub>).

The objective of this study is to identify the potential, opportunities and obstacles for using tax instruments to reduce emissions of the five non CO<sub>2</sub> greenhouse gases. The study covers every source of each of the non CO<sub>2</sub> gases, but has not researched the gases in the level of detail that would be needed if taxation were to be considered in any individual OECD country. The objective of this work is to provide initial indications of the feasibility of taxation.

The principle behind environmental taxation is that prices should reflect the full cost of the activity concerned, so ideally a tax on greenhouse gases should reflect the environmental impact of the emissions as closely as possible. It is not feasible for a tax to exactly reflect the environmental impact of increasing concentrations of greenhouse gases in the stratosphere because of the uncertainties over the impacts. The next best option is to tax the emissions themselves. However, in many cases some proxy for the emissions is the only feasible event to place a tax on. Some activities may not be amenable to taxation because there are too many taxable entities with small levels of emissions, or because the measurement of emissions is uncertain making monitoring difficult. Many taxation systems focus on entities above a certain size in order to ensure that monitoring and administration costs are reasonable but that the majority of the emissions are covered.

Over the last decade, several countries have already chosen to tax CO<sub>2</sub> emissions. Other countries are expected to consider this measure as a tool to help them to meet their Kyoto commitments. Taxes on CO<sub>2</sub> are relatively straightforward. The relationship between fuel sold and CO<sub>2</sub> emissions is clear, which enables the carbon tax to be placed on fuel sales. Thus CO<sub>2</sub> taxes can be placed at a point and on a substance that is already taxed in most if not all developed countries. Although the emissions themselves are not taxed, fuel consumption is an excellent proxy for the environmental impact of CO<sub>2</sub> emissions.

The potential for taxing other gases will depend largely on whether they can be monitored accurately and at reasonable cost, or whether there are proxies that relate closely enough to emissions and that can be monitored. Another factor is whether other policies and measures (or technical solutions) are better tools for addressing the emissions. Taxation will be one tool among many for addressing these emissions. The appropriate policy mix will depend on national circumstances. Another consideration is the contribution which the gases make to the global warming problem. Sources that make a very small contribution to global warming may not be worth addressing through a tax system unless the tax can be tacked on to an existing measure easily.

In national emission inventories, emissions are estimated based on emission factors that are applied to activity data such as landfill capacity, amount of fertiliser used or number of ruminant animals.

The accuracy of activity data differs among countries. Many OECD countries calculate their own emission factors. Where this is not possible, Intergovernmental Panel on Climate Change (IPCC) default emission factors can be used. Monitoring for taxation purposes need not follow the inventory approach and may well require much higher standards of monitoring or measurement of emissions than is currently carried out. However, the experience of inventory preparation is instructive in terms of measurement feasibility. IPCC inventory information and expert papers have been drawn on extensively for this study.

## 1.2 Structure of the Study

The *Executive Summary* presents a summary of the main conclusions of the study on how well-suited different sources of non CO<sub>2</sub> greenhouse gases are to taxation. The sections following this introduction discuss sources and possibilities for taxing CH<sub>4</sub> (*Section 2*), N<sub>2</sub>O (*Section 3*) and HFCs, PFCs, and SF<sub>6</sub> (*Section 4*). A summary table of information that is needed to assess the feasibility of taxation is included at the end of every section. *Section 5* presents the conclusions of the study.

## 1.3 Nature of Non CO<sub>2</sub> Greenhouse Gases

*Table 1.1* below summarises the main features of the greenhouse gases that are controlled under the Kyoto Protocol. Their lifetime in the stratosphere, their global warming potential, and the sources of these emissions vary enormously.

**Table 1.1. Description of Gases**

Greenhouse Gas	Chemical formula	Lifetime (Years)	GWP (100 years)	Sector/Use
Carbon dioxide	CO <sub>2</sub>	Variable	1	Fossil fuel combustion (coal, oil, gas), some industrial processes, eg. cement production.
Methane	CH <sub>4</sub>	12 +/-3	21	Fuel combustion (stationary; mobile); coal mining; oil and gas production; agriculture (livestock production, rice cultivation, agricultural burning); landfilling; waste water
Nitrous oxide	N <sub>2</sub> O	120	310	Fuel combustion (stationary, mobile); adipic and nitric acid production; agriculture (fertilisers, livestock waste management, nitrogen fixing crops).
HFC-23	CHF <sub>3</sub>	264	11,700	By-product of HCFC-22, used in very low temperature refrigeration; component in fire suppression equipment; plasma etching and cleaning in semiconductor production.
HFC-32	CH <sub>2</sub> F <sub>2</sub>	5.6	650	Component of numerous refrigerants.
HFC-41	CH <sub>3</sub> F	3.7	150	*
HFC-43-10mee	C <sub>5</sub> H <sub>2</sub> F <sub>10</sub>	17.1	1,300	Cleaning solvent.
HFC-125	C <sub>2</sub> H <sub>2</sub> F <sub>5</sub>	32.6	2,800	Component of numerous refrigerants and a fire suppressant.
HFC-134	C <sub>2</sub> H <sub>2</sub> F <sub>4</sub>	10.6	1,000	*
HFC-134a	CH <sub>2</sub> FCF <sub>3</sub>	14.6	1,300	Most widely used refrigerant; component of other refrigerants; propellant in metered dose inhalers and aerosols; foam blowing agent.
HFC-152a	C <sub>2</sub> H <sub>4</sub> F <sub>2</sub>	1.5	140	Blend component of refrigerant blends and aerosol propellant.
HFC-143	C <sub>2</sub> H <sub>3</sub> F <sub>3</sub>	3.8	300	*
HFC-143a	C <sub>2</sub> H <sub>3</sub> F <sub>3</sub>	48.3	3,800	Component in refrigeration.
HFC-227ea	C <sub>3</sub> HF <sub>7</sub>	36.5	2,900	Fire suppressant and propellant for metered dose inhalers.
HFC-236fa	C <sub>3</sub> H <sub>2</sub> F <sub>6</sub>	209	6,300	Refrigerant and fire suppressant.
HFC-254ca	C <sub>3</sub> H <sub>3</sub> F <sub>5</sub>	6.6	560	Foam blowing agent and refrigerant.

Greenhouse Gas	Chemical formula	Lifetime (Years)	GWP (100 years)	Sector/Use
Sulphur hexafluoride	SF <sub>6</sub>	3,200	23,900	Gas used in magnesium production and casting; insulating gas and insulator in electric power equipment; fire suppression discharge agent in military systems; atmospheric and subterranean tracer gas; sound insulation; process flow rate measurement; medical applications.
Perfluoromethane	CF <sub>4</sub>	50,000	6,500	By-product of aluminium production; plasma etching and cleaning in semiconductor production, and low temperature refrigerant.
Perfluoroethane	C <sub>2</sub> F <sub>6</sub>	10,000	9,200	By-production of aluminium production; plasma etching and cleaning in semiconductor production.
Perfluoropropane	C <sub>3</sub> F <sub>8</sub>	2,600	7,000	Low temperature refrigerant; fire suppressant.
Perfluorobutane	C <sub>4</sub> F <sub>10</sub>	2,600	7,000	Fire suppressant.
Perfluorocyclobutane	c-C <sub>4</sub> F <sub>8</sub>	3,200	8,700	*
Perfluoropentane	C <sub>5</sub> F <sub>12</sub>	4,100	7,500	*
Perfluorohexane	C <sub>6</sub> F <sub>14</sub>	3,200	7,400	Precision cleaning solvent.

Source: The Handbook of Environmental Chemistry (1999) Vol 4 Part E, Pg 139. IPCC (1995). The Science of Climate Change. Pg 22. IPCC (1995) Guidelines for National Greenhouse Gas Inventories, Vol 3.

Note: \*No information is available from IPCC on the sources of these chemicals.

The Global Warming Potential (GWP) index provides a simple measure of the relative effects of greenhouse gases on global warming. CO<sub>2</sub> has been given a GWP value of 1 over a 100 year period. Other gases can be multiplied by their GWP to give their CO<sub>2</sub> equivalent in global warming potential terms over a 100 year period. The GWP values for non CO<sub>2</sub> greenhouse gases vary from 21 to over 23,000.

Although there are inherent uncertainties over GWP values (for example derivation of GWPs requires knowledge of the fate of the emitted gas and the radiative forcing due to the amount remaining in the atmosphere), 100 year GWP values are the standard index used by UNFCCC Parties in preparing their national inventories. GWP values will be used to aggregate emissions of all greenhouse gases for assessing compliance with developed country emission reduction commitments under the Kyoto Protocol.

The following sections address the nature of each gas, describe the very varied sources of each gas, and make a preliminary assessment of the feasibility of using tax instruments to limit emissions.

## 2. METHANE (CH<sub>4</sub>)

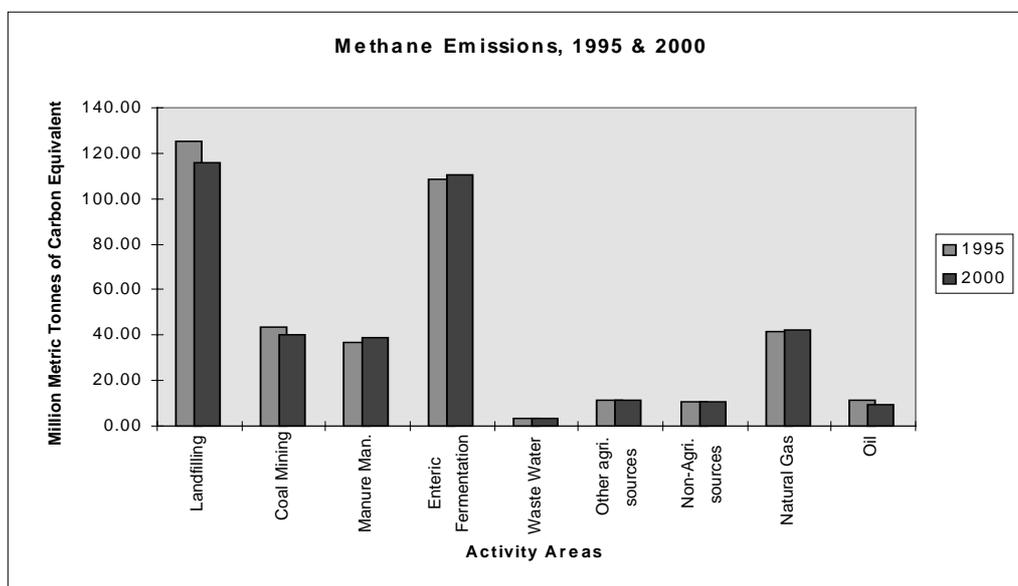
### 2.1 Overview

CH<sub>4</sub> is the most important non CO<sub>2</sub> greenhouse gas. It is estimated to account for 20% of anticipated global warming from current levels of emissions. Some CH<sub>4</sub> emissions occur naturally. For example large quantities are produced from anaerobic decomposition of organic matter in wetlands. However, the contribution of human (anthropogenic) activities to concentrations of CH<sub>4</sub> in the atmosphere is growing. <sup>(2)</sup>

CH<sub>4</sub> remains in the atmosphere for around 12 years and has a GWP of 21, which means that a gram of CH<sub>4</sub> contributes 21 times more to global warming than a gram of CO<sub>2</sub> over a 100 year period. <sup>(3)</sup>

The main anthropogenic (human) sources of CH<sub>4</sub> are: landfills; waste water treatment; waste incineration; coal mining; natural gas and oil production; livestock (enteric fermentation); rice cultivation; agricultural residue burning; land conversion; savannah burning; and fossil fuel combustion. *Figure 2.1* below shows the contributions of each of these sources of CH<sub>4</sub> to total CH<sub>4</sub> emissions in OECD countries.

**Figure 2.1. Methane Emissions from Different Sources in the OECD**



Source: US Environmental Protection Agency (1998) (draft).

Notes: "other agricultural sources" includes: rice cultivation, agricultural residue burning, land conversion and savannah burning; "non-agricultural sources" includes: stationary and mobile fuel combustion, waste incineration.

2. IPCC. Climate Change 1995.
3. *ibid.*

It is technically possible, although expensive, to measure CH<sub>4</sub> emissions. One method involves collecting the gas in a closed chamber. Another method is to use a tracer gas, most commonly SF<sub>6</sub>. The rate at which CH<sub>4</sub> emissions occur along with the inert tracer is known and the concentration ratios of the two gases downwind can be related to the ratio of their fluxes. This method is restricted to situations where there are no interfering emissions and sufficiently high CH<sub>4</sub> concentrations in the air to permit measurement far enough down wind to ensure adequate mixing with the tracer gas.

It is more practical to use activity data (such as quantity and type of landfilled waste, number of animals, and area of land under rice cultivation) which is multiplied by an emission factor to give an estimate of emissions. Emission factors can be estimated based on measurements in the field. Alternatively, the IPCC guidelines provide default emission factors. <sup>(4)</sup>

## 2.2 Emissions from Landfills

The anaerobic decomposition of waste in landfills is a major source of CH<sub>4</sub> world-wide and in OECD countries. This constitutes the largest source of CH<sub>4</sub>. <sup>(5)</sup> The amount of CH<sub>4</sub> that is generated from landfills depends on the quantity and composition of the waste (particularly the proportion of organic matter) and the type of landfill. The data on municipal solid waste generation and composition in countries with good data collection systems can have an uncertainty range of plus or minus 10 to 20%. The figures on non-municipal solid waste are even less certain.

There are a number of mitigation options that can be used to change landfill management practices, to change the type of landfills that are built (for new sites), and to reduce waste quantities (or the proportion of organic matter being landfilled). For example, in the UK, a tax has been placed on inactive or inert wastes that is landfilled. Inert waste (which does not give off gases when landfilled) incurs a charge of £2 per tonne and all other waste incurs a charge of £7 per tonne. The UK also offers tax credits for landfill operators who spend money on specified environmental objectives. <sup>(6)</sup> The Netherlands requires by regulation that landfills must be designed with CH<sub>4</sub> capture systems and that it must be used as energy or combusted. There are also EU Directives on recovery of packing waste that EU Member States must comply with.

In Japan, the Government promotes the importance of CH<sub>4</sub> recovery through education and information. In the USA the government has set standards that require large landfills to capture and combust emissions. In the USA there are also voluntary agreements between the government and industry to reduce waste and packaging, and to recycle waste. The primary objective of these policies is not related to global warming but these measures will have an impact on greenhouse gas emissions.

### 2.2.1 Landfill management

An important measure for reducing emissions from existing landfills is the introduction of good practice in managing landfills. For example, manipulation of landfill cover soils to maximise their oxidation potential could provide a viable strategy for controlling CH<sub>4</sub> emissions at older sites where the

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4. IPCC (1995), Vol 3.

5. US Environmental Protection Agency (1998) (Draft)

6. 90% of any contribution can be reclaimed up to a maximum of 20% of an operators annual landfill tax liability. The other 10% of funding must come from the landfill operators or from a third party.

CH<sub>4</sub> concentration in landfill gas is too low for energy recovery.<sup>(7)</sup><sup>(8)</sup> Landfill gas from modern landfills can be collected and used, vented, or flared (flaring results in CO<sub>2</sub> emissions that have a much lower GWP). Emissions from landfills in many OECD countries are expected to decrease due to improved waste management practices and pollution control measures.

Taxing CH<sub>4</sub> emissions from landfills may be feasible at newer landfills where emissions can be measured or monitored at reasonable cost. The feasibility of this would need to be considered on a case-by-case basis. An emissions tax, payable by landfill operators, would provide incentives for a range of management practices. It would encourage flaring rather than venting CH<sub>4</sub> emissions. Landfill operators would have an incentive to think of less CH<sub>4</sub> intensive ways of managing landfills. An emissions tax might provide the necessary incentive for landfill operators to charge more for organic matter than for inert waste, although this would depend on how landfill pricing regulations work in each country or city, and on whether the organic matter is readily identifiable.

A tax on CH<sub>4</sub> from modern landfills could also be designed to encourage collection of the gas for use as an energy source. Local heating and power generation are possible uses for gas that is collected. Where direct local use of the gas is not possible electricity can be generated using the gas as a fuel, at an efficiency of 30 to 40%.<sup>(9)</sup> Landfill gas has high CO<sub>2</sub> content and low calorific value which make it unsuitable for natural gas distribution systems. However, it is possible to upgrade the gas so that it can be used in distribution systems.

A tax on CH<sub>4</sub> from modern landfills might also encourage the operators to incinerate waste rather than landfilling biodegradable material although this tends to be expensive (over \$200/ton<sup>(10)</sup>) and results in other greenhouse gas emissions (CO<sub>2</sub> and small quantities of N<sub>2</sub>O) and other environmental damage.

### **2.2.2 Construction of new landfills**

The types of landfill in OECD countries vary greatly depending on how old they are. Modern sanitary landfills are deeper, use compaction, have well operated leachate and storm water systems, frequent surface covering, and gas control and recovery. Older landfills can be open dumps with shallow disposal, limited compaction, no or limited covering, frequent fires and scavenging. Most sites fall between these two extremes. When new landfills are constructed there is an opportunity to require that certain features are built into them to enable better management practices and collection of CH<sub>4</sub>. CH<sub>4</sub> taxation would encourage construction of landfills that produce less CH<sub>4</sub> or enable it to be collected. However, regulations are a likely measure for ensuring that any new landfills are built to modern standards. If regulations are in place a tax would have little additional effect on the type of landfills that are constructed, although it might generate incentives for further innovation.

### **2.2.3 Waste minimisation**

Options for reducing the amount of waste going to landfill include recycling and re-use of goods and household composting, and reductions in the amount of material used in products that are later

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7. Waste Age (1998).

8. An important control on net methane emissions in landfills is the rate of methane oxidation in cover soils. The physical properties of the cover soil (moisture, porosity etc) control the transport of oxygen methane and nutrients to microbial communities in the soil.

9. IEA (1999).

10. *ibid.*

landfilled. Taxes on household and industrial waste are one option for encouraging waste minimisation. Other options that could be used as an alternative to taxes, or in conjunction with them, are regulations (eg to limit material used in packaging) and education or information measures to inform householders of the benefits of composting organic matter.

## **2.3 Emissions from Livestock**

The majority of agricultural CH<sub>4</sub> emissions in developed countries are from enteric fermentation in ruminants. The number of animals, type of feed and climate all influence emissions. Anaerobic decomposition of manure is also a source of CH<sub>4</sub>. Anaerobic conditions usually occur at large confined animal management facilities that manage and store manure as a liquid.

There are few examples of measures to reduce CH<sub>4</sub> emissions from livestock in the selected OECD countries reviewed for this study. The Netherlands reports that policies to reduce nitrate and ammonia emissions under the Common Agricultural Policy are expected to result in a decrease of cattle numbers and/or a decrease in nitrogen excretion per animal. In the USA, the Environmental Protection Agency uses workshops, decision support software, standards on methane recovery systems, and a marketing programme to encourage large scale animal waste producers (dairy and swine) to recover and re-use methane from the waste. <sup>(11)</sup>

### **2.3.1 Reducing animal numbers**

Future demand for livestock products will be a primary driver of emissions from enteric fermentation. A tax per animal that reflects the average CH<sub>4</sub> emissions per animal is a possibility. Information on animal numbers is already collected in many OECD countries although verification of this information may be costly. Data on livestock numbers are likely to be available from sales and abattoir data. A tax on meat products at consumer level is also possible, although this would not reflect animal management methods that influence emissions. However, livestock industries in many developed countries are undergoing significant restructuring. Production subsidies are being reduced and continued subsidy reduction is the logical first step. This trend is likely to limit future livestock production.

### **2.3.2 Higher quality feed**

The main technical option for reducing the emission intensity of livestock is to change to higher quality feeds, that improve animal growth, productivity and reproduction. Sales taxes are already levied on animal feed products, which makes the addition of another tax on lower quality feeds to reflect CH<sub>4</sub> emissions feasible. Differential sales taxes could be used to encourage use of high quality feeds. However the differential would have to be significant given the cost of high quality feed. Another difficulty is that higher quality feeds increases animal waste which is a source of N<sub>2</sub>O emissions. N<sub>2</sub>O has a higher GWP value than CH<sub>4</sub> and longer atmospheric lifetime. Given the uncertainties in the data, it is very difficult to estimate what the net effect would be.

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11. Under the AgStar Voluntary programme, US Climate Change Action Plan 1993, p. 41.

### 2.3.3 *Reducing emissions from manure*

In OECD countries, CH<sub>4</sub> emissions from manure arise mainly from pig and dairy farming. Emissions from this source are significant due to high animal densities and the widespread use of lagoons for disposal and anaerobic digestion. Local environmental concerns about nitrogen related emissions are changing manure management practices in some OECD countries and this tends to reduce the CH<sub>4</sub> intensity of manure. However, the overall trend is towards increasing emissions of CH<sub>4</sub> due to the increasing number of large confined animal facilities that treat manure anaerobically.

More efficient capture of emissions from lagoons or the use of dung as fuel could help to reduce emissions from animal waste. Shifts in manure management practices towards dry systems would produce less CH<sub>4</sub> than liquid systems. Digestors enhance the anaerobic decomposition of organic material, and maximise the amount of CH<sub>4</sub> that is produced inside the reactor for recovery. An anaerobic digester with gas capture is estimated to reduce CH<sub>4</sub> emissions by two thirds or more. Emission reduction can also be achieved through covering manure storage areas or storage in cool places. Covered storage areas can also be used to capture gas that can then be used as energy.

The difficulty of measuring emissions from manure and of monitoring emissions from a large number of farms may preclude taxation as a tool for addressing CH<sub>4</sub> emissions from this source.

## 2.4 **Emissions from Coal Mining**

The geological processes involved in forming coal produce substantial quantities of CH<sub>4</sub>. Undisturbed coal seams may contain up to 25 cubic metres of CH<sub>4</sub> per tonne of coal. Coal extraction tends to lead to the release of more CH<sub>4</sub> than was originally trapped within the mined coal seam itself because the drop in pressure draws in additional gas from surrounding strata.

Elimination of production subsidies and measures to reduce CO<sub>2</sub> emissions make it less important to consider taxation as a tool to addressing CH<sub>4</sub> from coal mining.

### 2.4.1 *Underground coal mining*

Underground mined coal produces around 90% of the total CH<sub>4</sub> emissions from coal mining. Most of this is released to the atmosphere through mine ventilation systems which are required to ensure the safety of the mines, which provides a way to measure the emissions from this source.<sup>(12)</sup> Some emissions arise from CH<sub>4</sub> drainage schemes that are designed to reduce the requirements for ventilation at some underground mines with particularly high CH<sub>4</sub> gas levels.

Emissions from underground mining can be addressed by removing as much CH<sub>4</sub> as possible prior to mining or by capturing the CH<sub>4</sub> as it is released, during and after coal production. CH<sub>4</sub> removed directly from coal beds is generally of high purity. In many cases it could be supplied directly to a natural gas distribution system. It also could be used for power generation or heating. CH<sub>4</sub> drained from the coal during or after production is of variable quality.

Technologies for capturing CH<sub>4</sub> emissions from coal mining are well developed. Much of the captured CH<sub>4</sub> is vented or flared. Potentially, 50% of CH<sub>4</sub> from coal mining could be captured and all

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12. Coal mine methane is a safety hazard because it is highly explosive in ambient concentrations between 5 and 15%.

unused gas could be flared rather than vented. The costs of CH<sub>4</sub> capture vary from under \$100 per ton to over \$350 per ton CH<sub>4</sub> (approximately \$5 to \$15 per ton of CO<sub>2</sub>). At the lower end of this range, it can be cost-effective to use captured CH<sub>4</sub> as a form of energy. <sup>(13)</sup>

CH<sub>4</sub> emissions from ventilation systems are mostly vented to the atmosphere, although in a few cases a small fraction is used to provide combustion air for on site generators or heaters. These emissions cannot be flared because the concentration is too low. Technology could be developed to destroy these emissions. With heat recovery for power generation, the net costs of CH<sub>4</sub> oxidation should be small, and this technology could lead to significant reductions in emissions. <sup>(14)</sup>

Emissions from coal mining are very specific to the geology of each mine and mining practices. Mine specific measurement from ventilation and degasification systems produces accurate measures of emissions. It is therefore likely that emissions from venting systems at underground mines could be measured and monitored adequately for taxation purposes. <sup>(15)</sup> The Australian national inventory estimates that mine ventilation data is accurate to within plus or minus 20%. Frequent measurement could reduce this uncertainty. However, the economics of producing coal in OECD countries are becoming less favourable.

#### **2.4.2 Surface mining**

Open cast mining releases CH<sub>4</sub> directly to the atmosphere, but because the seams are close to the surface they contain little of their original CH<sub>4</sub>. Measurement of emissions from surface mining is technically difficult and expensive. An alternative is to base the estimate on the gas content of surface coal. However the gas contents of surface coal can vary greatly within a country, and would therefore require mine specific measurements. There are very few measurement data on which to base emission factors for post mining activities and the uncertainty is high.

CH<sub>4</sub> emissions also occur during post mining handling, processing and transportation of coal. These emissions are estimated to be low, although higher than total emissions from surface mining. <sup>(16)</sup>

### **2.5 Natural Gas and Oil Systems**

CH<sub>4</sub> is emitted from leaks and from venting from oil and gas systems. CH<sub>4</sub> emissions occur throughout many parts of these systems, in production fields, gas processing facilities, gas transmission lines, gas distribution lines and oil storage facilities.

Emissions from natural gas and oil systems constitute a significant share of total CH<sub>4</sub> emissions in OECD countries, as illustrated in *Figure 2.1* above. These emissions are expected to increase as production of natural gas and oil increases and as gas is transported longer distances by pipelines. <sup>(17)</sup>

With existing technology, it may be possible to prevent over 80% of current emissions from the oil and gas industry globally by the year 2010. <sup>(18)</sup> Higher levels should be possible as abatement

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13. IEA (1999).

14. *ibid.*

15. IPCC (1999) (B).

16. *ibid.*

17. US Environmental Protection Agency (1998).

18. IEA (1999).

technologies continue to develop. It is estimated that 45% of emissions from this sector could be avoided at little or no net cost. A further 12% could be avoided at a cost of up to \$400/tonne of CH<sub>4</sub> (\$19 per tonne of CO<sub>2</sub>), mainly by flaring associated gas that cannot be used in any other way. <sup>(19)</sup>

The main policy options used in the OECD countries reviewed for this study are voluntary agreements and direct government funding. In the UK, the government has entered into an agreement with the operator of the natural gas network to achieve a 2% decrease in CH<sub>4</sub> leakage rates (by improved maintenance). The UK has also issued best practice guidelines for limiting emissions from oil and gas installations. In the Netherlands the government has funded replacement of gas distribution networks and improvement of gas pipeline maintenance. In the USA, there is a voluntary programme for the industry to reduce emissions from gas production and processing.

### 2.5.1 *Natural gas*

One of the largest contributors to CH<sub>4</sub> emissions from natural gas systems is leakage during gas compression which is essential for gas transmission. Booster compressors are required on pipelines at intervals of typically 100 to 150 kilometres. There are also substantial CH<sub>4</sub> emissions from purging pipelines, valve leakage and leakage through seals, especially in older installations. It is technically feasible to make substantial reductions in emissions from all the main sources in many cases simply by applying current best practice when older equipment requires replacement. Local air quality regulations, particularly for NMVOCs, will encourage gas distribution companies to reduce leaks and venting. Newer equipment tends to leak less than older equipment.

Natural gas production is also a significant source of methane. Calculation of methane loss from natural gas production is typically based on calculations in methane mass balances and the measurement error can easily be greater than the magnitude of the methane loss. <sup>(20)</sup>

Given the range of other measures used to address CH<sub>4</sub> emissions from natural gas systems, the commercial incentives to reduce losses, and the difficulty of measuring emissions, these systems are not obvious candidates for specific greenhouse gas taxation measures.

### 2.5.2 *Oil*

The majority of emissions from the oil industry are due to venting or flaring CH<sub>4</sub> emissions that occur during oil extraction. To reduce these emissions, the CH<sub>4</sub> must be re-injected or flared rather than vented. Efficient flaring reduces emissions by 98% compared with venting. Flaring is preferable to venting for safety reasons and is often required by law, but even where such requirements are in place, a tax could provide an additional incentive for further innovation. Taxes could also encourage re-injection of gas into the oil field which would sequester the emissions. However re-injection can enhance oil production and so would be carried out by oil companies where this is cost-effective in any case. Depending on whether other measures and incentives are already in place, it may be worth considering taxation as an instrument to address CH<sub>4</sub> emissions from oil and gas production. A few large companies produce oil and gas and their emissions are technically feasible to monitor.

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19. *ibid.*

20. "Potential of Including Non-Combustion Sources of GHG Emissions in a Domestic Emissions Trading Program" [NRTEE, Jan. 1999, Ottawa, p71].

The methane content of the oil in each well is known from chemical analysis. However it is very difficult to measure methane leaks from well-heads on a regular basis so rough emission factors are used for the entire sector, not for each individual site. <sup>(21)</sup>

## 2.6 Emissions from Waste Water

Municipal and industrial waste water is a small source of CH<sub>4</sub> in OECD countries. Waste water treatment plants are a significant source of emissions. CH<sub>4</sub> emissions also arise from partially or wholly untreated waste water discharged into surface water but little is known about the quantity of emissions from untreated sources. <sup>(22)</sup>

Organic material in waste water produces CH<sub>4</sub> when it decomposes anaerobically. Industrial sources generate the majority of CH<sub>4</sub> emissions, especially food processing, pulp/paper making and the chemical industry. In OECD countries most municipal and industrial waste water is collected and treated in an integrated sewage system. Treatment involves an aerobic degradation step and emissions of CH<sub>4</sub> are therefore low.

Taxation is unlikely to be a useful instrument for this source of emissions due both to the relative insignificance of the source and measurement difficulties.

## 2.7 Emissions From Other Agricultural Sources

This category includes rice cultivation, agricultural residue burning, land conversion and savannah burning. These are relatively small sources of emissions in most OECD countries as illustrated in *Figure 2.1* above.

CH<sub>4</sub> emissions in rice cultivation primarily arise through plant growth and anaerobic decomposition of organic material in flooded rice fields. Irrigated rice and continuously flooded rain-fed rice are rice eco-systems that produce the greatest amount of CH<sub>4</sub>. Upland rice is not a source of CH<sub>4</sub> since it is grown in aerated soils that never become flooded for a significant period of time. Differences in residue recycling, organic amendments, scheduled short aeration periods, soils, fertilisation and rice cultivars are major causes for variations of CH<sub>4</sub> fluxes in irrigated rice.

The easiest mitigation option is selection of suitable rice cultivars, which could cut emissions by 20 to 30%. Emissions could also be reduced by using inorganic fertilisers in place of the organic fertilisers that are often used. This could reduce CH<sub>4</sub> emissions by up to 50% but may increase N<sub>2</sub>O emissions. Soil additives could be used to suppress nitrifying bacteria with the benefit of increasing soil fertility and increasing rice yields. <sup>(23)</sup>

Emissions of CH<sub>4</sub> are produced only when the ground is flooded. Changes in water management practices could help reduce emissions. Intermittent irrigation to give shallow flooding every three to five

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21. Potential of Including Non-Combustion Sources of GHG Emissions in a Domestic Emissions Trading Program" [NRTEE, Jan. 1999, Ottawa, p71].
  22. IPCC (1995), Vol 3.
  23. IPCC (1999) (C).

years can reduce CH<sub>4</sub> emissions by up to 50%. This technique is likely to be difficult to implement since in many cases it will involve a radical change in agricultural practices. <sup>(24)</sup>

Emissions from rice production do not appear to be a good candidate for taxation. The use of rice cultivars and agricultural residue as organic fertiliser would be costly to monitor for taxation purposes. They are produced as a result of the agricultural activity itself and rice farmers could misreport quantities used. It may be possible in some countries to tax irrigation water if it is metered. A tax could be placed on sales of domestic rice and rice exports. Where rice cultivation is subsidised removing or redesigning the subsidies is an option although this can be politically difficult.

Changing agricultural management practices is likely to need to be supported by public information and awareness campaigns. In some countries, for example Japan, strong cultural values are attached to traditional rice cultivation and it will be difficult to change behaviour. Observed seasonal CH<sub>4</sub> emissions from rice fields in different countries show large ranges: from 1g/m<sup>3</sup> to 155 mg/m<sup>3</sup>. <sup>(25)</sup> Country-specific emission factors take into account different water management regimes, incorporation of specific organic amendments and specific conditions of continuous flooding in the absence of any organic amendments. These emission factors are highly uncertain even when measured carefully. <sup>(26)</sup>

Incomplete combustion from burning activities, to clear land or as part of agricultural practice, results in CH<sub>4</sub> emissions. Emissions of CH<sub>4</sub> (and N<sub>2</sub>O) from biomass burning are dependent on the vegetation and combustion efficiency. Burning of biomass for agricultural purposes or for land conversion (more of a concern in developing countries) is difficult to monitor and therefore not amenable to tax instruments.

## 2.8 Emissions from Non Agricultural Sources

This category includes fossil fuel combustion from stationary and mobile sources, waste incineration, biomass fuel combustion and miscellaneous industrial processes. These are very small sources of CH<sub>4</sub> emissions. Emissions are influenced by the amount of fuel combustion and the combustion technology used.

Measures to reduce CH<sub>4</sub> emissions from fossil fuel combustion include the introduction of three way catalysts in vehicles and reducing the use of fossil fuels. A CH<sub>4</sub> component could be added to existing fuel taxes or CO<sub>2</sub> taxes relatively easily. However, it is very difficult to accurately estimate the emissions because they are affected by a range of factors such as driving conditions.

## 2.9 Conclusions: Possible Taxable Events for CH<sub>4</sub>

*Table 2.1* summarises key features of CH<sub>4</sub> producing activities that relate to the feasibility of using tax instruments to address them.

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24. IEA (1999).

25. *ibid.*

26. *ibid.*

**Table 2.1. Preliminary Screening of Taxable Events for CH<sub>4</sub>**

Activity	Quantity of taxable entities	Importance	Ease of measurement/ monitoring	Emissions projection from 1995 to 2000 (per cent)*
Landfilling	Many	Very high	Good	-8
Coal mining	Medium	High	Good (for underground mining)	-9
Oil and natural gas systems	Few	Medium	Poor	3
Oil and natural gas transmission	Few	High	Reasonable	
Gas distribution	Medium	Medium	Poor	
Enteric Fermentation	Many : farmers	Very high	Poor	1.6
Livestock production	Many: farmers	Medium	Poor	5.5
Waste water treatment	Many	Low	Poor	0.7
Other agriculture	Many	Low	Reasonable	-3
Other (Fuel combustion)	Many	Low	Reasonable	-0.1

\* Source: US EPA, 1998 (draft)

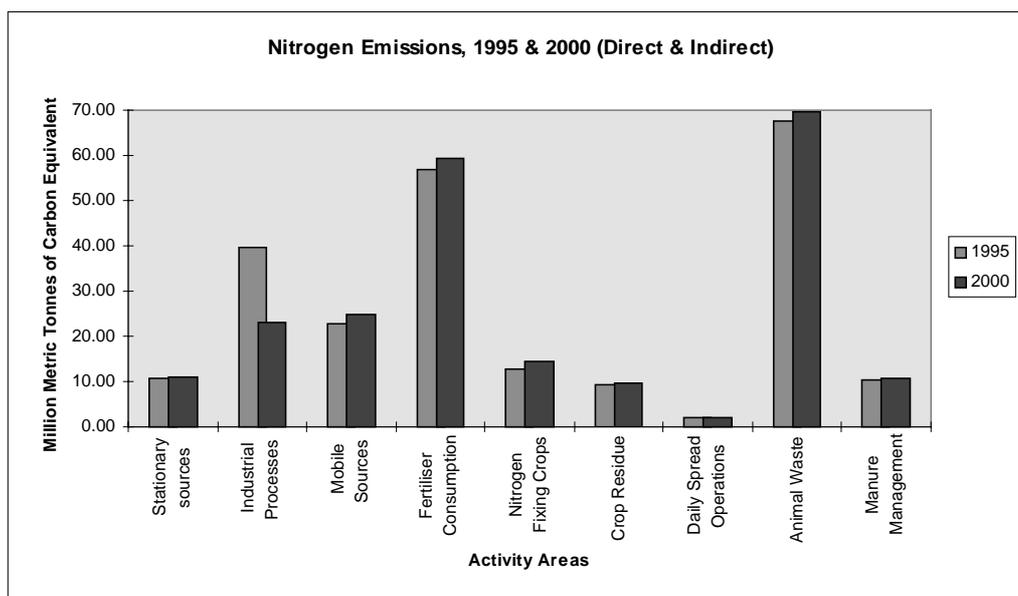
### 3. NITROUS OXIDE (N<sub>2</sub>O)

#### 3.1 Overview

There are many small sources of N<sub>2</sub>O which are difficult to quantify. The main anthropogenic sources of N<sub>2</sub>O are agriculture and a number of industrial processes. N<sub>2</sub>O has a lifetime of 120 years and a GWP value (over a 100 year period) of 310. The sources of N<sub>2</sub>O are: agricultural soils (fertiliser application and manure management); industrial processes; and fuel combustion. <sup>(27)</sup>

Figure 3.1 below shows the contributions of each of these sources to total N<sub>2</sub>O emissions in OECD countries.

**Figure 3.1. N<sub>2</sub>O Emissions by Source in the OECD**



US Environmental Protection Agency, 1998 (draft)

Many N<sub>2</sub>O mitigation options revolve around good agricultural practice rather than lowering emissions from organic and non-organic fertilisers. For example:

- improving soil drainage;
- reducing simultaneous slurry and nitrogen fertiliser applications;
- acidification of cattle slurry to reduce denitrification;

27. IPCC (1995), Vol 3.

- composting poultry manure with wood chips or straw gives significant reductions in the rate of denitrification; and
- matching nitrogen applications to seasonal plant demands to minimise surplus nitrate/ammonium in soil layers.

IPCC experts are reconsidering the calculation of emission factors due to evidence that management and seasonal variables may affect emissions of N<sub>2</sub>O from agricultural soils.

### 3.2 Fertilisers

N<sub>2</sub>O is produced naturally in soils through the microbial processes of denitrification and nitrification.<sup>(28)</sup> Many factors regulate nitrification and denitrification, such as: soil moisture and temperature; the amount of mineralisable organic carbon (used as an energy source for denitrifiers); soil oxygen availability (which controls denitrification); the presence in the soil of suitable mineral nitrogen substances (ie ammonium and nitrate); and soil pH.

A major driver of anthropogenic N<sub>2</sub>O emissions is the addition to agricultural soils of mineral nitrogen fertilisers and the application of animal manure or of readily decomposable plant residues that are rich in nitrogen.

Fertiliser use accounts for more than 85% of the ammonium nitrate end use market. Indirect additions occur through volatilisation and subsequent atmospheric deposition of ammonia and oxides of nitrogen that originate from the application of fertilisers, and surface runoff and leaching of nitrogen from the same sources. Seasonal weather variation, management variables and crop type have a large impact on N<sub>2</sub>O fluxes.

There are policies in place in OECD countries to control fertiliser use. In OECD countries, fertiliser consumption is often regulated to protect rivers and lakes. Fertiliser consumption is expected to decline in OECD countries because of concerns about nitrates in the water supply.

Taxation could complement other measures. Fertilisers already have taxes levied on them in some countries. In addition there are relatively few sources of fertiliser production, which makes monitoring easier. Farmers will purchase less fertiliser, provided there are cheaper and viable alternatives. One alternative farmers could choose is to modify agricultural management to minimise the potential for denitrification and nitrification to occur. Government education campaigns could encourage this. Another alternative is the use of manure, or sewage sludge from waste water treatment plants, in place of inorganic fertiliser. Measures may be needed to discourage this alternative as it would increase emissions of N<sub>2</sub>O.

Controlled-release fertilisers tend to be used more efficiently by plants, although more expensive to purchase. Nitrification inhibitors may have a role in reducing emission through maintaining added nitrogen as ammonia.

### 3.3 Animal Waste

Direct nitrogen applications occur through various cropping practices such as application of fertilisers, production of nitrogen fixing crops, the incorporation of crop residues into the soil and the

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<sup>28</sup>. Denitrification is the anaerobic reduction of nitrate to molecular dinitrogen gas. Nitrification is the aerobic oxidation of ammonium to nitrate during decomposition of organic matter.

cultivation of high organic content soils, and through livestock waste management (these include direct deposition of animal waste and spreading operations). Animal waste management systems contribute around a third of N<sub>2</sub>O emissions from agriculture. <sup>(29)</sup> <sup>(30)</sup>

Accurate measurement of N<sub>2</sub>O emissions can be obtained for animal waste management systems through direct measurements. However, there are numerous, small and diffusely spread sources to measure. Activity data for livestock production and crop production systems are generally well documented in most countries in- and outside the OECD. Data on animal waste management systems are less well documented. The uncertainty surrounding the emission factors for different animal waste management systems and different categories of animals is high. <sup>(31)</sup>

N<sub>2</sub>O emissions from livestock waste are closely related to livestock numbers. A reduction in livestock numbers could be achieved through a tax on livestock. To minimize monitoring costs, the tax could be levied on the delivery of animals to slaughterhouses. Taxes on meat products are another option for reducing meat consumption and which would indirectly reduce N<sub>2</sub>O emissions.

The EU has requirements that limit numbers of cattle, for example, milk production quotas and the EU set aside policy under which farmers receive subsidies for retiring land from agriculture. Voluntary approaches such as those used by the US could be combined with taxation at consumer level or production level.

### 3.4 Industrial Processes

N<sub>2</sub>O is emitted from adipic acid and nitric acid production processes. Adipic acid is the main constituent of nylon and is also used in the manufacture of synthetic fibres, coatings, plastics, urethane foams, elastomers and synthetic lubricants and polyesters. The US is a major producer of adipic acid, with four plants that account for around half of world production. Other producing countries include Canada, France, Germany, Japan, Norway, Ukraine and the United Kingdom. Most of these countries have only one adipic acid plant. Capacity expansion is occurring in North America and Western Europe as well as in the Asia-Pacific region. Global adipic acid production is expected to total nearly 2.3 million metric tones in 2000, compared to 1.8 million metric tones in 1995. However, emissions are projected to decrease substantially by 2000 because all adipic acid manufactures are intending, for commercial reasons, to install technology that reduces N<sub>2</sub>O emissions by 90-99% depending on plant specifications. <sup>(32)</sup> There is therefore little point taxing N<sub>2</sub>O emissions from adipic acid manufacture.

Nitric acid is the second largest industrial source of N<sub>2</sub>O emissions. Nitric acid is an inorganic compound which is generated as a by-product of the high temperature catalytic oxidation of ammonia and used primarily to make the synthetic commercial fertiliser, ammonium nitrate. It is also a major component in the production of adipic acid and explosives.

Some nitric acid plants recycle N<sub>2</sub>O for use in other phases of the facility.

Many nitric acid production facilities are between 20 and 30 years old, so there are opportunities to update emissions control technologies or install new ones. IPCC reports that there is also plenty of scope

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29. IPCC (1999) (I).

30. There are six categories of animal waste management systems: anaerobic lagoons, liquid systems, daily spread, solid storage and drylot, pasture range and paddock.

31. IPCC (1999) (I).

32. IPCC (1999) (G).

for emissions reduction in nitric acid manufacture. <sup>(33)</sup> Nitric acid plants are few and N<sub>2</sub>O emissions can be monitored so N<sub>2</sub>O taxation could be considered for this industry.

The accuracy and precision of N<sub>2</sub>O emission factors for industrial processes depend on the number of samples and the frequency of sample collection. Plant level characteristics such as the range of process variability and the state of technology affect emission factors. Continuous emission monitoring is the most accurate approach, but it is expensive and requires inspection and maintenance of the equipment. The calculation of a plant specific emissions factor which relates the mass rate of N<sub>2</sub>O generation to the production rate of adipic acid or nitric acid can be an accurate alternative to continuous monitoring if it is based on periodic sampling.

### **3.5 Fuel Combustion**

#### **3.5.1 Introduction**

N<sub>2</sub>O is a product of the reaction that occurs between nitrogen and oxygen during fossil fuel combustion.<sup>(34)</sup> Mobile and stationary sources emit N<sub>2</sub>O and the volume emitted varies according to the type of fuel, the size and vintage of the combustion technology, pollution control device used, ambient conditions as well as maintenance and operating practices.

#### **3.5.2 Mobile sources**

N<sub>2</sub>O emissions are closely related to air and fuel mixes and combustion temperatures as well as to the use of pollution control equipment on vehicles. Road transport accounts for the majority of mobile source fuel consumption and hence emissions. The introduction of catalytic converters has led to a significant change in the emissions of some pollutants. Catalysts reduce emissions of NO<sub>x</sub> and CO and CH<sub>4</sub> but increase N<sub>2</sub>O emissions and fuel consumption (and hence increase CO<sub>2</sub> emissions).

N<sub>2</sub>O emissions from mobile sources will continue to rise as the amount of transport increases. There are a range of alternative fuels including LPG, CNG, Bio-diesel, Ethanol/Methanol, electric and fuel cells. Most of these technologies are becoming available but are currently more costly than conventional fuels. Other barriers to these fuels include fuel distribution and vehicle availability. Improved fuel economy will reduce N<sub>2</sub>O emissions. This is particularly relevant for freight traffic where there is significant scope for efficiency improvements.

There are two different approaches to the reduction of N<sub>2</sub>O emissions from road transport: reducing the emissions intensity of vehicles or reducing the total stock of vehicles. Fuel taxes should have an impact on consumer demand for less fuel-intensive vehicles (although factors influencing consumer demand are complex). Alternatively, higher taxes could be levied on inefficient vehicles than on those with better fuel economy. Road taxes or registration taxes could be differentiated for smaller and larger engine sizes. Taxes could also be 'piggy backed' onto existing consumption taxes for fossil fuels.

There exist relatively few data to estimate N<sub>2</sub>O emission factors for gasoline vehicles. Emission factors have been determined for early and advanced three way catalysts. These emission factors reflect

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33. *ibid.*

34. N<sub>2</sub>O is emitted during the combustion of natural gas, fuel oil, coal, wood and other fuels such as LPG, waste oil, coke oven gas, coke and non-residential wood.

conditions in the US. There is a large uncertainty for emission factors relating to N<sub>2</sub>O and activity data (such as vehicle kilometres driven for different road and fuel types).<sup>(35)</sup>

### 3.5.3 Waste incineration

Waste incineration is another source of N<sub>2</sub>O. In industrialised countries the proportion of waste burned in incineration plants can be very high. *Table 3.1* below shows the amount of municipal waste incinerated in waste incineration plants.

**Table 3.1. Municipal Waste Incineration in Western Europe**

Country	Incineration capacity per country Mg x 10 <sup>6</sup> / yr	No of Municipal Solid Waste incinerators
Austria	0.513	3
Belgium	2.24	24
Denmark	2.31	30
Finland	0.07	1
France	11.33	225
Greece	0	0
Germany	14	59
Ireland	0	0
Italy	1.9	28
Luxembourg	0.125	1
Netherlands	3.15	10
Norway	0.5	18
Portugal	0.5	2
Spain	0.74	14
Sweden	1.86	21
Switzerland	2.84	30
UK	3.67	31
<b>Total</b>	<b>45.748</b>	<b>497</b>

Source: IPCC (1999) (H)

N<sub>2</sub>O emission levels have been estimated at individual municipal solid waste incineration plants, with an average of 1-2 mg/m<sup>3</sup>. From hazardous waste incineration plants the emission levels increase to 30-32 mg/m<sup>3</sup>. N<sub>2</sub>O emission levels are significantly higher in the incineration of sewage sludge in fluidised bed plants (around 100 mg/m<sup>3</sup>). Data are available on incineration capacity per country and the number of incinerators for OECD countries. Broad emissions factors could be used to estimate the amount of N<sub>2</sub>O from waste incineration but would not be accurate. Most emissions policies for waste incineration are regulations that require specific types and standards of equipment to be used. Therefore taxation would not be a likely policy choice for these emissions.

### 3.6 Conclusions: Possible Taxable Events for N<sub>2</sub>O

*Table 3.2* summarises key features of N<sub>2</sub>O producing activities that relate to the feasibility of using tax instruments to address them.

35 IPCC (1999) (J).

**Table 3.2. Preliminary Screening of Taxable Events for N<sub>2</sub>O**

<b>Activity</b>	<b>Quantity of taxable entities</b>	<b>Importance</b>	<b>Ease of measurement /monitoring</b>	<b>Emissions Projection from 1995 to 2000 (per cent)*</b>
Stationary fuel combustion	Many	Reasonable	Poor	13.5
Mobile sources	Many	Medium	Poor	10
Adipic acid	Few	High	Good	-58 (adipic and nitric)
Nitric acid	Few	High	Good	“
Fertilisers (direct)	Many	High	Poor	3
Daily spread operations	Many	Low	Poor	4
Direct deposition of animal waste (direct)	Many	Very high	Poor	4
Manure management	Many	Low	Poor	2.5

\*Source: US EPA (1998) (draft)

## 4. FLUORINATED COMPOUNDS: HFCS, PFCS, AND SF<sub>6</sub>

### 4.1 Overview

The concentrations of PFCs, HFCs and SF<sub>6</sub> are currently small. However, they are forecast to increase (scenario IS92a) and could contribute about 3% of the total radiative forcing from all greenhouse gases by 2100. <sup>(36)</sup> Most of the current emissions are from developed countries.

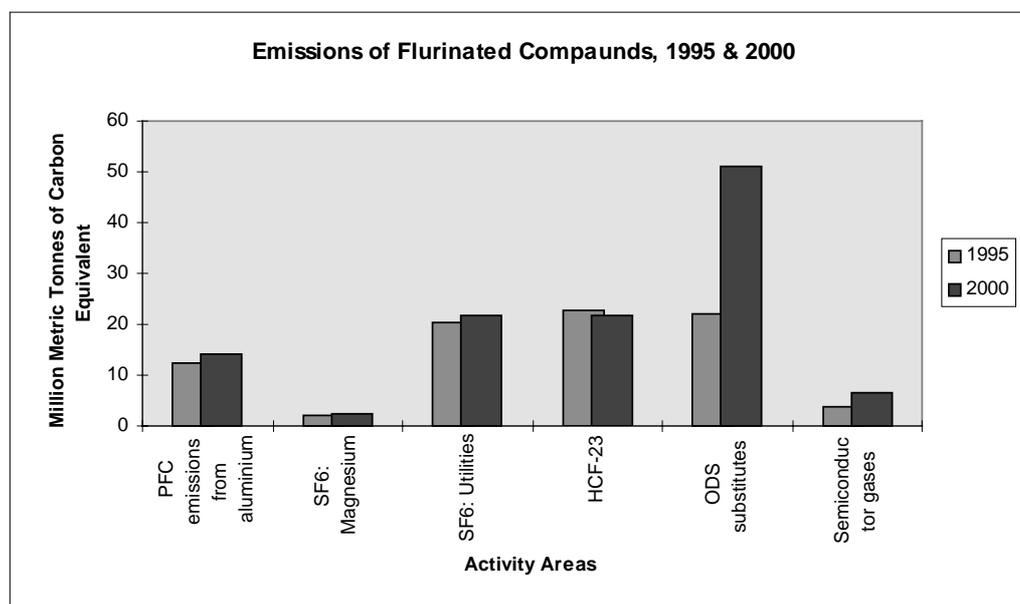
The main sources of fluorinated compounds are: fugitive emissions of HFCs from HCFC production; use of HFCs and to some extent PFCs as ozone depleting substance replacements; use of PFCs in primary aluminium production; consumption of SF<sub>6</sub> (for example, in magnesium production and electrical products); and use of all three gases in the semiconductor industry. *Figure 4.1* below indicates the emissions from each of these sources in OECD countries for 1995 and 2000. The comparison between 1995 and 2000 demonstrates the rapid growth in the use of ozone depleting substance replacements over this period. The expected growth in their use together with their extremely powerful GWP values make them important gases to mitigate.

Halocarbons are carbon compounds containing fluorine, chlorine, bromine and iodine. For most of these compounds human activities are the sole source. Halocarbons that contain chlorine (CFCs and HCFCs) and bromine cause ozone depletion and their emissions are controlled under the Montreal Protocol. Their use has fallen under the Montreal Protocol phase-out schedule and HFCs are being used to replace ozone depleting substances (ODS) in some applications. HFC-23 is generated as a by-product of HCFC-22 arising from over-fluorination during the manufacture of HCFC-22. HFCs have very varied GWP values and lifetimes, as shown in *Table 1.1* at the start of this paper.

PFCs and SF<sub>6</sub> are removed very slowly from the atmosphere with estimated lifetimes greater than 1000 years (CF<sub>4</sub> has a lifetime of 50,000 years).

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36. Six emission scenarios were published in the 1992 Supplementary Report to the IPCC Assessment (Leggett *et al*, 1992). These scenarios projected how future greenhouse gas emissions might evolve in the absence of climate policies beyond those already adopted. IS92a represents a middle of the range scenario.

**Figure 4.1. Emissions of HFC, PFC, and SF<sub>6</sub> from Various Sources in the OECD**

Source: US EPA, (1998) (draft)

#### 4.2 HFC-23 from HCFC-22 Production

HFC-23 is produced during the production of HCFC-22. The quantity emitted depends on how the process is operated and how well optimised the process is. Over 90% of sales of HCFC-22 are for refrigeration and air conditioning. Much of this production occurs in OECD countries. HCFC-22 is also used as a component in foam blowing, and as a chemical feedstock for manufacturing synthetic polymers. Research in the UK shows that plants that are not fully optimised to reduce HFC-23 generation produce HFC-23 emissions in the order to three to four per cent of HCFC-22 production. However emissions can be reduced to around 1.5 to 3% of production with two per cent being an average estimate. *Table 4.1* below summarises HCFC-22 production from OECD countries.

**Table 4.1. Sources of HCFC-22 Production in OECD Countries**

Country	1995 estimate (metric tonnes)
USA	155,000
Japan	59,000
Germany	29,000
United Kingdom	26,000
Netherlands	19,000

Source: IPCC (1999) (L)

74% of HCFC-22 production is accounted for by the countries indicated in *Table 4.1*. The US produces around 50% of the production of HCFC-22 in developed countries with four plants. Japan is the next largest producer.

The major emissions point for HFC-23 in the HCFC-22 production process is the condenser vent where it is discharged to the atmosphere after separation from the HCFC-22. It is estimated that 98-99% of

the HFC-23 that is generated is emitted at this point. <sup>(37)</sup> HFC-23 emissions can be estimated but they vary according to specific plant infrastructure and operating conditions. Periodic sampling can be highly accurate. <sup>(38)</sup> Continuous emission monitoring of HFC-23 would be accurate if the measuring devices are calibrated and operated properly, but it can be expensive.

In developed countries the scheduled phase out of HCFC-22 production will occur by 2020 due to requirements under the Montreal protocol. Feedstock production however is permitted to continue. Production in developing countries will be phased out over a longer time period. Since HCFC-22 is being phased out under the Montreal Protocol, there seems little point in placing a tax on HFC-23 from this activity, although a tax could accelerate the phase-out.

### 4.3 Ozone Depleting Substance (ODS) Replacements

HFCs are now commonly used as alternatives to the ODS that are being phased out under the Montreal Protocol. Alternatives must be found primarily for CFC-12, the most common refrigerant, but increasingly for HCFC-22, in refrigeration and air conditioning. ODS are used in a number of industrial applications including refrigeration and air conditioning equipment, aerosols, solvent cleaning, fire extinguishing, foam production and sterilisation. HFCs do not convey chlorine to the stratosphere and hence are not implicated in ozone depletion. The major alternative fluorocarbons are HFC-134a and HFC-32. PFCs are also used as alternatives to ODS, but due to their cost are not likely to be used to the same extent as HFCs. For mobile air conditioning, fewer alternatives are available. Butane and propane appear to be promising as HFC-134a substitutes but some substitutes may increase energy use of equipment involved.

There are clear growth trends in demand for refrigeration which is likely to remain an end use for fluorocarbons. Long term extrapolation for both CFC-12 and HCFC-22 shows that the peak requirements for both compounds together would have reached 1.1 million tonnes per year by the middle of the next century without the Montreal Protocol phase-out. Total historic production for all CFCs, for all uses other than as solvent was 15.4 million tonnes of which refrigeration used 7.1 million tonnes. <sup>(39)</sup>

The use of HFCs and PFCs as ODS replacements is forecast to grow significantly (see *Table 4.2*).

**Table 4.2. Emissions Scenario for Halocarbon Gases (kt)**

Gas	Use	2000	2050	2100
HFC 134a	Refrigeration and foam blowing	94	654	686
HFC 245ca	Foam blowing	0	222	232
HFC 125	Refrigeration	5	50	53
HFC-143a	Refrigeration	5	50	53
PFC-218	Refrigeration	1	20	21

Source: The Handbook of Environmental Chemistry Vol. 4 Part E, Pg 149

However there are many alternative substances and methods of production that can be used to replace HFCs and PFCs. Current indications are that substitution by fluorocarbons actually will be

37. IPCC (1999) (L).

38. *ibid.*

39. Hand book of Environmental Chemistry Vol. 4 Part E (1999) , Pg 147.

significantly less than 50%.<sup>(40)</sup> HFCs may only account for 15% of the ODS replacement market in the near future. *Table 4.3* below lists non greenhouse gas alternatives for ODS.

**Table 4.3. Substitutes for current uses of CFCs**

Use	CFC now used	Expected compound	Alternative agent	Alternative process
Aerosol propellant	CFC-11 CFC-12		<ul style="list-style-type: none"> <li>• Hydrocarbons</li> <li>• Carbon dioxide</li> <li>• Nitrogen</li> <li>• N<sub>2</sub>O</li> <li>• Air pressure</li> <li>• Dry powder inhalers</li> </ul>	<ul style="list-style-type: none"> <li>• Non spray</li> <li>• Mechanical vaporisers</li> </ul>
Metered dose inhalers	CFC-11 CFC-12	HFC-134a		Different delivery systems
Domestic refrigeration	CFC-12	HFC-134a	<ul style="list-style-type: none"> <li>• Hydrocarbons (butane, propane, LPG)</li> <li>• Ammonia</li> <li>• Helium</li> </ul>	<ul style="list-style-type: none"> <li>• Reduced leaking</li> <li>• Vapour compression with water vapour or hydrocarbons</li> <li>• Stirling cycle with helium</li> <li>• Absorption systems with ammonia and water, or water and lithium bromide</li> <li>• Absorption systems with zeolite and water</li> </ul>
Mobile air conditioning	CFC-12	HFC-134a	<ul style="list-style-type: none"> <li>• Zeolite and water, or propane/butane</li> <li>• Hydrocarbons</li> <li>• Carbon dioxide</li> </ul>	Absorption systems with zeolite and water
General and commercial refrigeration and air conditioning	CFC-12  R-502 <sup>(41)</sup> and HCFC-22	HFC-134a HCFC-22 HFC-152a Mixtures containing HFC-32 HFC-125 HFC-134a	<ul style="list-style-type: none"> <li>• Ammonia</li> <li>• Hydrocarbons</li> <li>• Air</li> </ul>	
Large scale air conditioning	CFC-11 CFC-12	HCFC-123 HFC-134a	Adsorption ammonia	
Solvent	CFC-113	HCFC-141b	<ul style="list-style-type: none"> <li>• Hydrocarbons</li> <li>• Water</li> </ul>	
Plastic foam	CFC-11 CFC-12	HCFC-141b HCFC-142b	<ul style="list-style-type: none"> <li>• Hydrocarbons</li> <li>• Water</li> <li>• Carbon dioxide</li> </ul>	<ul style="list-style-type: none"> <li>• Vacuum panels</li> <li>• Water vapour blowing</li> </ul>
Fire extinguisher	Halon-1211	HFC-227ea	<ul style="list-style-type: none"> <li>• Dry powder</li> <li>• Carbon dioxide</li> <li>• Water</li> <li>• Foam</li> <li>• Carbon dioxide</li> <li>• Nitrogen</li> </ul>	<ul style="list-style-type: none"> <li>• Construction adaptation, faster detection appliances</li> <li>• Loss reduction methods</li> <li>• Improved object safety instead of total flooding</li> </ul>

Source: The Handbook of Environmental Chemistry, Vol. 4, Part E, Pg 139, Department of Environment, Ireland.(1998)

Taxation would be feasible for ODS replacements if emissions of ODS are taken to be equal to consumption of the substances (as is assumed in many national emission inventory estimates). To use consumption of ODS as the taxable event does not take into account efforts made by product manufacturers to reduce leakage or prolong the life of the product that they manufacture. It would be

40. *ibid.*

41. R-502 is a mixture of CFC-115 and HCFC-22.

complex to base the tax on the correct level of emissions released from the leakage and disposal of the products. The measurement of actual chemicals released is complex and data intensive. The number of equipment units that use these substances must be estimated, along with average chemical charges, average service life, emission rates, recycling and disposal. The chemicals that are used in products will be released at some point and consumption is a reasonable proxy for emissions.

The least costly points at which to place a tax is likely HFC and PFC production or sales or both (since emissions occur during both the production and use of the chemicals in products). There are relatively few production companies to monitor. Sales taxes would be incurred by manufacturers of products that contain ODS replacements (again a reasonably small number of companies) and would be passed onto the consumers of the products such as fridge/freezers.

Other measures that have been implemented to address these gases are regulatory restrictions on the amount of HFC leakage in refrigeration equipment in the Netherlands, and voluntary restrictions on the use of HFCs and PFCs in products in the US. Taxation could complement, or replace, regulatory approaches to address leakage.

#### **4.4 PFCs from Primary Aluminium Production**

Aluminium production is the primary anthropogenic source of two of the most important PFCs ( $\text{CF}_4$  and  $\text{C}_2\text{F}_6$ ). Anode effects occur in aluminium production when, during the smelting process, the alumina ore content of the electrolyte bath falls below critical levels required for electrolysis and rapid voltage increases occur. These anode effects cause carbon from the anode and fluorine from the dissociated molten cryolite bath to combine, producing fugitive emissions of PFCs. The magnitude of the emissions depends on the frequency and duration of these anode effects.

Factors that influence PFC generation in this process include cell technology types, cell operating parameters (anode effect frequency, anode effect duration, anode effect voltage, etc), anode effect kill routine and electrolyte properties. The emissions per tonne from aluminium production can be drastically reduced by better design of the cell and its control system.

In 1996, 44 countries produced aluminium with an annual production of 20.7 million metric tonnes. Aluminium production is expected to double over the next 100 years and so emissions of PFCs from the aluminium industry will also grow from their current levels (approximately 14,600 tonnes per year of  $\text{CF}_4$  and 1,900 tonnes per year of  $\text{C}_2\text{F}_6$ ).<sup>(42)</sup>

It is possible to estimate the PFC emissions but emissions of  $\text{CF}_4$  and  $\text{C}_2\text{F}_6$  vary significantly from one aluminium sector to the next depending on cell type and anode effect parameters. Unless emission measurements have been made at the smelter level, emissions estimates will be highly uncertain. Most aluminium producing countries have a relatively small number of aluminium facilities. Verification would be needed for each smelter to establish the relationship between PFC emissions and operating parameters in order to accurately estimate PFC emissions. Few countries regulate PFC emissions, but one example is regulations limiting PFC emissions from aluminium smelting in the UK. In Norway, a voluntary agreement with industry to reduce PFCs has led to significantly reduced emissions.

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The Handbook of Environmental Chemistry Vol 4 Part E, Pg 145-146.

#### 4.5 Semiconductor Industry

Semiconductors, or integrated circuits, act as the brains for electronic controls and devices and are widely used in consumer and industrial equipment. Examples of products that use semiconductors are computers, vehicles, appliances, buildings and industrial processes. The semiconductor industry uses long lived fluorinated gases in plasma etching and chemical vapour deposition (CVD) processes. The gases most commonly used are HFC-23, PFCs ( $\text{CF}_4$  and  $\text{C}_2\text{F}_6$ ) and  $\text{SF}_6$ , although other compounds are also used. These compounds allow manufacturers to accurately etch the patterns on these metal and dielectric layers, and to perform rapid chemical cleaning processes.

In addition to being directly used in manufacturing processes, fluorinated compounds are also transformed during the process to form other compounds. For example,  $\text{CF}_4$  is generated and emitted as a process by-product when  $\text{C}_2\text{F}_6$  is used either for cleaning or etching. The amount of  $\text{CF}_4$  produced can be 10 to 30% of the  $\text{C}_2\text{F}_6$  input depending on the cleaning process.

Semiconductors are produced by about 400 companies around the world in 1,100 plants ranging in size from small research and development sites to large production plants. Not all plants use fluorinated compounds to manufacture semiconductors. Generally, very small semiconductor devices require manufacturing process steps that utilise fluorinated compounds. In 1996, 900 metric tonnes of fluorinated compounds were purchased by the US semiconductor industry for use at around 170 plants (around half of total semiconductor plants in the US). A medium size US manufacturing plant has around 60 etching and CVD tools. As semiconductor devices increase in complexity so does the quantity of fluorinated compounds required for manufacture.

The semiconductor industry is expected to grow significantly. Sales of fluorinated compounds to the US semiconductor industry over the 1990 to 1996 period show a compounded annual growth rate across all species of around 30%. This rapid growth is due to increased world-wide demand for semiconductor devices, the increase in semiconductor device complexity and the lack of viable alternatives for fluorinated compounds. <sup>(43)</sup>

Direct continuous measurement of emissions is not feasible for the semi-conductor industry. Measurement of emission factors are typically made under what is called centerline process conditions (nominal flow, power and pressure etc). Once operating in full production many manufacturers alter process conditions from the centerline conditions.

HFC, PFC and  $\text{SF}_6$  inputs, semiconductor production capacity data and sales data are not good proxies for actual emissions. Emissions vary with plant utilisation, product type and complexity. Measurement of actual fluorinated gas emissions from semiconductor manufacture is difficult and costly depending on the level of accuracy required. The manufacturing process may require up to 100 steps that use fluorinated compounds and up to 3 months process time. Some emissions are generated as a product of a transformation of gases and therefore the GWP of an emission stream coming out may be a lot higher than the GWPs of the original gas inputs. Thus taxing sales of HFCs, PFCs and  $\text{SF}_6$  to the semiconductor industry will not reflect actual emissions.

#### 4.6 Sulphur Hexafluoride

$\text{SF}_6$  is manufactured by six major global producers, who account for the majority of global supply. The companies and the locations of their major plants are:

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43. IPCC (1999) (N).

Asahi Glass Chemicals	Japan
Kanto Denka Kogyo	Japan
AlliedSignal Inc.	USA
Air Products & Chemicals	USA
Ausimont	Italy
Sovay Fluor und Derivate GMBH	Germany

About 80% of the use of SF<sub>6</sub> is in electrical transmission and distribution systems.<sup>(44)</sup> This includes gas insulated switchgear and circuit breakers, gas insulated high voltage transmission lines and mini-stations. Fugitive emissions can escape from gas insulated substation and gas insulated circuit breakers through seals, especially from older equipment. SF<sub>6</sub> can also be released when equipment is opened for servicing.

SF<sub>6</sub> emissions from magnesium production are around ten per cent of total current SF<sub>6</sub> emissions.<sup>(45)</sup> SF<sub>6</sub> is used in foundries for die casting to prevent oxidation of the molten magnesium. Small concentrations of SF<sub>6</sub> in combinations with CO<sub>2</sub> and air are blown over the molten magnesium to induce the formation of a protective crust.

SF<sub>6</sub> is also used (in “adiabatic applications”) in tennis balls, shoe soles and truck tyres (largely Germany). SF<sub>6</sub> is also used as gas air tracer in research, as a leak detector for medical purposes, in electronic applications, and soundproof windows.<sup>(46)</sup> *Table 4.4* below summarises the sources of SF<sub>6</sub>.

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44. IPCC (1999) (O).

45. IPCC (1999) (Q).

46. IPCC (1999) (O).

**Table 4.4. Source Categories by Country/Region**

Source	Tonnage (per cent) of total SF <sub>6</sub> production	Country / Region	Quantity (ton)
Electrical equipment manufacture	3500 (42)	USA	140
		Europe	1200
		Japan	1400
		Russia	500
		China	350
Refill by electricity utilities	1500 (18)	USA	700
		Europe	400
		Japan	370
Magnesium industry	400 (5)	USA	260
		Canada	60
		Norway	35
Semiconductor industry	300 (4)	USA	110
Truck tyres	140 (2)	Japan	70
Tennis balls, soles of sporting shoes	220 (3)	Germany	140
		USA	110
Soundproof windows	270 (4)	Japan	70
		Germany	1700
Other applications	340 (5)	USA	90
		Japan	50
		Germany	25
Miscellaneous (scientific applications, military applications, additional refill of utility equipment, additional consumption for magnesium production)	1700 +/- 600 (23)	USA	1200 +/- 400
		Europe	500 +/- 200

IPCC (1999) (O)

Current policy efforts to address SF<sub>6</sub> emissions appear to be concentrated in the magnesium production sector. Some examples of policies that have been implemented to address SF<sub>6</sub> emissions are: local air pollution control guidance in the UK on how to minimise SF<sub>6</sub> emissions from magnesium foundries; research into SF<sub>6</sub> use and mitigation in Japan, and voluntary agreements with the industry in the US to reduce SF<sub>6</sub> emissions from the magnesium industry. <sup>(47)</sup>

#### 4.6.1 Magnesium

Primary magnesium is normally produced in a molten state from electrolytic decomposition of magnesium chloride and is cast continuously into ingots under a protective atmosphere. High pressure die casting is the process of casting magnesium parts by injecting molten magnesium into a mould clamped together by hydraulic force. Die casting is the most common and economical form of magnesium casting due to its high casting rates and the long life of the dies. World wide, die casting is the second largest end use for magnesium, estimated at over 85 kt in 1997. This segment operates under multiple year contracts and is highly price competitive and therefore has the potential for significant operational shifting between plants and countries. Plants typically operate 5 to 20 furnaces in a variety of sizes. All furnaces must be supplied with SF<sub>6</sub> from a central mixing station through a distribution piping network. Three distinct processes are hot chambered die casting, cold chambered die casting and scrap re-melting. Each of these processes involves different operating conditions and may have different SF<sub>6</sub> consumption rates.

Gravity casting is a manual process where molten magnesium is usually poured manually into moulds composed of resin bound sand. It is used for highly complex castings requiring precision. Gravity casting requires as much as ten times the amount of SF<sub>6</sub> per tonne product that is used in die casting.

47. These examples are taken from these countries' national communications to the UNFCCC.

While some primary smelters operate their own recycling processes for returned used cast alloy materials, there are a number of independent magnesium recyclers who also use SF<sub>6</sub> for protection of molten magnesium. The secondary materials can be refined under SF<sub>6</sub> protection in the same type of refining and casting furnace used in primary metal, depending on the market requirement for the secondary metal.

Primary magnesium production is concentrated in around 10 countries in the world. Around two third of production comes from smelters located in six countries: USA (3), Canada (12), France, Norway, Serbia and Israel (each 1). China has many small capacity magnesium smelters. New magnesium capacity is being added in Canada, Iceland, Australia and the Congo in the next five years to meet the strong growth in magnesium die casting demand. 78% of total SF<sub>6</sub> is consumed in the US and Canada, 15% in Europe and 7% in the rest of the world.

There are around 30-35 die casters in North America. The US and Japan have over 90% of the estimated 100 kt of secondary magnesium production in the world. In the US there are around four or five major independent magnesium recyclers, some of which use SF<sub>6</sub>.

There is strong growth in magnesium production due to the high demand growth of magnesium die casting for the auto industry. Magnesium is rapidly displacing steel and aluminium in automotive parts applications, which account for over 85% of die casting demand. An offsetting trend is the increased adoption of best operating practices for reducing SF<sub>6</sub> consumption among producers and casters due to the high price of the gas and climate change concerns. Some smelters are testing alternative cover gas systems using SO<sub>2</sub> and claim that they will eliminate SF<sub>6</sub> use in the next few years.

SF<sub>6</sub> consumption rates for magnesium production are estimated to range from 0.5 to 4 kg/tonne magnesium produced. Emissions from the magnesium industry can be taken as being equal to consumption of SF<sub>6</sub>.<sup>(48)</sup> SF<sub>6</sub> consumption in the magnesium industry is easily measured. No significant conversion or destruction of SF<sub>6</sub> occurs in magnesium casting processes, so emissions can be taken as equal to inventory changes or measuring the difference in cylinder weight for gas used or returned.

Direct reporting of consumption is accurate and captures the majority of the SF<sub>6</sub> volume used in the magnesium industry. There are different tracking techniques that can be used by companies to record annual consumption. Usage rate of SF<sub>6</sub> varies widely from company to company and types of processes so emission factors should be gathered at plant level. Most companies already track consumption (for example, recording delivered purchases) and there are only a handful of primary magnesium producers and magnesium recyclers. Die casters are more numerous but still possible to monitor. SF<sub>6</sub> emissions from the magnesium industry appear to be a good candidate for taxation. The magnesium industry is, however, projected to have the smallest growth rate of all SF<sub>6</sub> emitting sources.

#### **4.6.2 Other applications**

The greatest growth in emissions is expected to come from manufacture of products such as tennis balls, sporting shoes and electrical products but monitoring SF<sub>6</sub> emissions from these products is difficult.<sup>(49)</sup> Emissions from these products are extremely uncertain and the number of manufacturers of these products is large. However, the sale of chemicals to these manufacturers of products could be used as a proxy for emissions.

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48. IPCC (1999) (Q).

49. IPCC (1999) (O).

Table 4.5 provides the uncertainty ranges that have been developed by IPCC experts for the default emission factors for SF<sub>6</sub> from various sources that.<sup>(50) (51)</sup>

**Table 4.5. Ranges of Uncertainty for SF<sub>6</sub> Emission Factors**

SF <sub>6</sub> source	Uncertainty (%)	Qualitative uncertainty
• Gas Insulated Switchgear (GIS) manufacturing prior to 1995 (Europe and Japan)	+/- 10	small
• GIS manufacturing from 1998 onwards (Europe and Japan); • GIS leakage plus maintenance for equipment manufactured before 1980 and for newer equipment (Europe); • GIS leakage plus maintenance for equipment manufactured before 1989 (Japan); • Adiabatic property applications for tyres; • Fire suppression and explosion protection in new portable equipment and new fixed equipment; • Manufacture of double glazing for soundproof windows*.	+/- 25	medium
• SF <sub>6</sub> production; • GIS leakage plus maintenance for equipment manufactured after 1980 (Japan); • Circuit breakers manufacturing*; • Circuit breakers leakage plus maintenance*; • Leakage rates for double glazing of sound proof windows*.	+/- 50	large
• Adiabatic property applications for applications other than tyres	+/- 100	very large

Source: IPCC (1999) (O)

Note: \* Uncertainty ranges are in themselves uncertain

#### 4.7 Conclusions: Possible taxable events for HFCs, PFCs, and SF<sub>6</sub>

Table 4.6 summarises key features of activities resulting in industrial greenhouse gas emissions that relate to the feasibility of using tax instruments to address them.

50 Uncertainty ranges have not yet been developed for emission factors relating to the insulation of high voltage transmission lines.

51 \* indicates that the uncertainty range is in itself uncertain.

**Table 4.6. Preliminary Screening of Taxable Events for HFCs, PFCs, and SF<sub>6</sub>.**

<b>Activity</b>	<b>Quantity of taxable entities</b>	<b>Importance</b>	<b>Measurement / monitoring potential</b>	<b>Emissions trend (% increase: 1995 to 2000)*</b>
ODS substitute	Many	High	Good (Can be complex for complete accuracy)	132
Production of chemicals	Few	High	Good	-
Consumption of chemicals	Many	High	Good	-
PFCs in the aluminium industry	Low	Medium	Good	13
SF use in magnesium production	Smelters: Few Die casters: Medium Recyclers: Few	Low	Good	19
SF <sub>6</sub> use in electrical equipment	Many	High	Uncertain	7
Semi conductor industry	Many	High	Uncertain	71
HFC-23	Few		Good	-5

\*US EPA (1998) (draft)

Just as for ODS, data from companies on production and consumption of HFCs, PFCs, and SF<sub>6</sub> may need to be handled in such a way as to ensure commercial confidentiality.

## 5. CONCLUSIONS

### 5.1 Introduction

The objective of this study is to provide initial indications of the feasibility of using tax instruments to reduce emissions of the five non CO<sub>2</sub> greenhouse gases: CH<sub>4</sub>; N<sub>2</sub>O; HFCs; PFCs; and SF<sub>6</sub>. The nature of these greenhouse gases varies enormously. Their lifetime in the stratosphere ranges from 1.5 to 50,000 years. Their global warming potential (over a 100 year period) ranges from 23 times the global warming potential of CO<sub>2</sub>, molecule for molecule, to over 23,000 times. There are also many varied sources of emissions for each gas which are summarised in *Table 1.1*.

This study covers every source of each of the non CO<sub>2</sub> gases. The study has not researched the gases in the level of detail that would be needed if taxation were to be considered in any individual OECD country. The assessment in *Sections 2 to 4* takes into account four factors: how complicated it is to estimate or measure the emissions; the number of taxable events; how large each emission source is in terms of current and expected future emissions; and whether other policies and measures are already in place to address the emissions. However, the concluding assessment in this section on which sources are most amenable (and which are least amenable) to taxation instruments rests largely on the number of taxable events and the ease of monitoring, measuring or estimating the emissions.

The most important sources of each non CO<sub>2</sub> greenhouse gas, in terms of quantities emitted, are:

- methane (CH<sub>4</sub>) from landfills, enteric fermentation in ruminants, natural gas and oil systems, and coal mining;
- nitrous oxide (N<sub>2</sub>O) from fertilisers and industrial processes;
- hydrofluorocarbons (HFCs) used in place of ozone depleting substances and HFC-23 as a by-product from production of HCFC-22;
- perfluorocarbons (PFCs) from anode effects during aluminium production; and
- sulphur hexafluoride (SF<sub>6</sub>) used in electrical equipment.

The feasibility of taxing these and other sources is discussed in *Section 5.2* and *5.3* below.

### 5.2 Possible Candidates for Taxation

#### 5.2.1 CH<sub>4</sub> from Oil and Gas Production

CH<sub>4</sub> is emitted during natural gas and oil production and can either be vented as CH<sub>4</sub>, combusted (flared), or re-injected into the oil/gas well (which can improve productivity). Flaring the CH<sub>4</sub> emissions converts the CH<sub>4</sub> to CO<sub>2</sub> which has a much lower global warming potential than CH<sub>4</sub>. Flaring activities are an important source of CH<sub>4</sub>, and the recent trend is for slight emissions growth. The IEA has estimated that

it may be possible to prevent over 80% of current emissions from the oil and gas industry globally by the year 2010, and that 45% of the emissions from this sector could be avoided at little or no net cost.

It is technically feasible to gather good quality data on emissions from oil and gas production. There are a small number of very large companies that produce oil and gas and their emissions are relatively easy to monitor. There is at least one example (Norway) of taxation of emissions from oil and gas production. A tax could be placed on both CO<sub>2</sub> and CH<sub>4</sub> emissions from oil and gas production, with a higher tax on CH<sub>4</sub>. Producers would then have a higher incentive to flare or re-inject the CH<sub>4</sub> emissions.

### **5.2.2 *CH<sub>4</sub> from modern landfills***

The anaerobic decomposition of waste in landfills is a major source of CH<sub>4</sub>. The amount of CH<sub>4</sub> that is generated from landfills depends on the quantity and composition of the waste but also on the type of landfill. Modern landfills typically include gas collection facilities. It is very feasible to apply a flow meter to the pipes and measure the amount of gas that is collected. Therefore it would be feasible to tax landfill operators for CH<sub>4</sub> emissions from newer landfills where emissions are typically required to be collected. Tax credits could be issued for gas that is collected and used as an energy source, and a lower tax could be charged for gas that is flared and so emitted to the atmosphere as CO<sub>2</sub>. However, care would be needed that taxes do not create disincentives to collection of the gas.

### **5.2.3 *CH<sub>4</sub> from underground coal mines***

Coal mining is an important source of emissions. It would be feasible to tax CH<sub>4</sub> emissions from underground coal mines, where the CH<sub>4</sub> that is released through venting systems can be collected or monitored relatively easily. However, a reduction in CH<sub>4</sub> emissions from underground coal mines is likely in OECD countries as a result of the increasing liberalisation of energy markets, leading to the removal of subsidies, and measures directed at the control of CO<sub>2</sub> emissions from fossil fuel energy, such as energy taxes. It may therefore not be necessary to tax CH<sub>4</sub> emissions from this source.

### **5.2.4 *N<sub>2</sub>O from Fertilisers***

N<sub>2</sub>O emissions from the use of fertiliser in agriculture vary depending on a number of factors (farm management practices, weather, and type of crop) so it is not feasible to tax these emissions directly. Emissions from fertiliser use are significant and the recent trend is for slight emissions growth. N<sub>2</sub>O emissions from the use of fertiliser in agriculture vary depending on a number of factors (farm management practices, weather, and type of crop) so it is not feasible to tax these emissions directly. However it would be feasible to place a tax on sales of fertiliser as a proxy for emissions. This would not reflect emissions accurately but would enable an important source of N<sub>2</sub>O emissions to be addressed. The tax could be combined with best practice guidelines and education programmes on crop management practices that release less N<sub>2</sub>O. Farmers would pay a tax on fertiliser that they buy. The tax could be differentiated so that controlled-release fertilisers (which are used more efficiently by plants) incur a lower tax. Data on fertiliser sales are readily available.

### **5.2.5 *HFCs used as ODS replacements***

Production of HFCs (primarily used as ODS replacements) could be monitored, although the data would have to come from the manufacturers. Sales of these substances should also be reasonably easy to monitor from sales statistics. A tax could be placed on HFC output from the manufacturers or on sales, and

could be differentiated to reflect the different GWPs of the substances. Data on production and sales of HFCs would have to be required from companies, and this could raise concerns unless the data are handled in a way that ensures commercial confidentiality. In addition, simplifying assumptions would have to be made about release of these gases to the atmosphere (eg consumption or use of these chemicals could be taken to be equal to emissions).

#### **5.2.6 *SF<sub>6</sub> use in magnesium and other processes (except semi-conductor manufacture)***

SF<sub>6</sub> emissions from the magnesium industry appear to be a good candidate for taxation. SF<sub>6</sub> consumption in the magnesium industry is easily measured. No significant conversion or destruction of SF<sub>6</sub> occurs in magnesium casting processes, so emissions from the magnesium industry can be taken as being equal to consumption of SF<sub>6</sub>. There are different tracking techniques that can be used by companies to record annual consumption. Usage rate of SF<sub>6</sub> varies widely from company to company and types of processes so emission factors would have to be gathered at the plant level. Most companies already track consumption (for example, recording delivered purchases). There are only a handful of primary magnesium producers and magnesium recyclers. Die casters are more numerous but still possible to monitor.

The magnesium industry is, however, projected to have the smallest growth rate of all SF<sub>6</sub> emitting sources. The greatest growth in emissions is expected to come from manufacture of products such as tennis balls, sporting shoes and electrical products. Monitoring SF<sub>6</sub> emissions from these products is difficult, but the sale of chemicals to these manufacturers of products could be used as a proxy for emissions. A tax could be paid by producers of SF<sub>6</sub> or by consumers such as magnesium producers, electricity distribution companies, and tennis ball manufacturers. Data on production and sales of SF<sub>6</sub> would have to be collected from producers.

#### **5.2.7 *Other industrial greenhouse gas sources***

Emissions of HFC-23 from HCFC-22 production will decline along with the phase out of HCFC-22 but taxing these emissions (or taxing HCFC-22 production itself) may boost the speed with which the ODS is phased out.

N<sub>2</sub>O from adipic acid manufacture could have been a candidate for taxation but huge (95%) reductions are occurring in emissions of N<sub>2</sub>O from adipic acid due to a technical change that is now best practice so the importance of emissions from this source is being dramatically reduced.

Taxing N<sub>2</sub>O from nitric acid production may be an option, as it is an important source of emissions with relatively few taxable events. There is scope for emissions reduction in nitric acid manufacture. Many nitric acid production facilities are between 20 and 30 years old, so there are opportunities to update emissions control technologies or install new ones. However monitoring or measuring the emissions would require plant by plant inspection. Similarly, taxing PFCs from the anode effects during aluminium production would have relatively few taxable entities, but would require plant specific emission measurements.

### **5.3 Greenhouse Gas Sources that are Least Suited to Taxation**

Important greenhouse gas emission sources that appear to be less well suited to taxation instruments are:

- CH<sub>4</sub> and N<sub>2</sub>O from fuel combustion;

- CH<sub>4</sub> from many existing landfills, natural gas distribution, surface coal mining, enteric fermentation, and rice production;
- N<sub>2</sub>O from agricultural soils and animal waste;
- HFCs, PFCs, and SF<sub>6</sub> used in semi-conductor manufacturing processes.

A CH<sub>4</sub> and N<sub>2</sub>O component could be added to existing fuel or energy taxes easily, but fossil fuel combustion is a very small source of these gases and measurement of the emissions is very imprecise.

Emissions from older landfills with no CH<sub>4</sub> recovery facilities are less amenable to monitoring and therefore to taxation. Measurement of CH<sub>4</sub> emissions from surface mining is technically difficult and expensive - it would require specific measurements at each mine. There are very few measurement data on which to base emission factors for post mining activities and the level of uncertainty is high. It is technically feasible to make substantial reductions in CH<sub>4</sub> emissions from natural gas distribution. However, because of the difficulty of measuring emissions from long stretches of pipeline these systems are not an obvious candidate for taxation measures.

Taxation may not be an appropriate tool for addressing CH<sub>4</sub> emissions from livestock and livestock manure due to the difficulty of measuring CH<sub>4</sub> emissions accurately and the cost of monitoring emissions from a large number of farms. N<sub>2</sub>O from livestock waste has similar measurement difficulties. CH<sub>4</sub> emissions from rice production also have measurement difficulties. Emission estimates would have to take into account different water management regimes, the amount and type of organic matter, and the specific conditions of continuous flooding. It may be possible in some countries to tax irrigation water if it is metered or a tax could be placed on sales of domestic rice and rice exports, but these would only indirectly address emissions.

It is very difficult to estimate emissions of HFCs, PFCs, and SF<sub>6</sub> from the semi-conductor industry as emissions vary with plant utilisation, product type and complexity. Consequently it would be difficult to place emissions taxes on this industry.

## **5.4 Questions that Arise from this Research**

### **5.4.1 *Source and country specific estimates of data quality***

Emissions of some non-CO<sub>2</sub> gases can be measured or estimated accurately. However understanding of non CO<sub>2</sub> greenhouse gas emissions is at an early stage compared to CO<sub>2</sub>. Experts are struggling to find ways to address the uncertainty in greenhouse gas emission estimates for national inventories. These uncertainties will have a detrimental effect on the use of taxation as an instrument to address these emissions at the site level. If industries (or individuals) are required to pay taxes, the importance of reliable emissions data at the site level (or acceptable proxies for emissions) increases. An area for further work is to assess the quality of emissions data site-by-site (or for a sample of sites) for the most important greenhouse gas sources in each OECD country.

### **5.4.2 *Interaction with existing policies and measures***

Another important question is how taxes on greenhouse gas emissions from various sources will interact with existing or planned policies and measures.

Some non CO<sub>2</sub> greenhouse gas emission sources are being addressed through other measures or are trending downwards without measures. It could nevertheless be more cost-effective to replace -- or supplement -- these measures with taxes. Sources that make a very small contribution to global warming may not be worth addressing through a tax system unless the tax can be tacked on to an existing measure easily.

Taxation will be one tool among many for addressing these emissions. In some cases other policies and measures (or technical solutions) may be better or more acceptable tools for addressing the emissions. The appropriate policy mix will depend on national circumstances.

Some existing policies may require monitoring that could be used or extended to monitor greenhouse gases. Other policies may require firms to install certain types of equipment that reduce emissions to such an extent that they limit the potential for further reductions in response to taxation. More detailed analysis at a country level is required to assess existing policies and measures that could help or hinder taxation.

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