NON-CO$_2$ GREENHOUSE GAS NETWORK INAUGURAL MEETING ON MITIGATION TECHNOLOGIES AND ECONOMIC ANALYSES

Report Number PH4/5
February 2002

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1. INTRODUCTION

The Non-CO$_2$ Greenhouse Gases Network was established by the US EPA[1], the European Commission[2] Directorate for Environment (EC DG Env.) and the IEA Greenhouse Gas R&D Programme (IEA GHG) in 2001. The objective of the network is to bring together an international team of leading researchers and policy advisors to compare data, mitigation technology analyses, economic modeling approaches and empirical results on the Non-CO$_2$ greenhouse gases.

The first meeting of the Non-CO$_2$ Greenhouse Gas Network was held in Brussels, Belgium on the 14th and 15th June 2001. The meeting was organized as a workshop providing technical presentations and opportunities for discussion. The workshop was entitled "Mitigation technologies and economic analyses". EC DG Env hosted the meeting, which was organised jointly with US EPA and IEA GHG. IEA GHG played the lead role in the development of the workshop programme and handled the detailed planning and organisation of the event.

The two-day workshop concentrated on establishing the state of research on mitigation technologies and economic analyses of abatement options for the Non CO$_2$ greenhouse gases. In particular, the aim was to compare the different methodologies used by various workers to express the economic indicators, e.g. marginal abatement cost curves. In addition, the meeting aimed to consider the best way for these data to be incorporated into economic models for predictive purposes.

The workshop was well attended with 45 delegates drawn from Europe, United States, Canada, Japan and South East Asia. An attendee list is provided in Appendix 1. There was a broad range of participation from governmental bodies, public research institutes, policy institutes, consulting groups and academia.

2. WORKSHOP SUMMARY

The workshop was divided into two sections. On the first day a series of presentations were made for, and on behalf of, the EC DG Env., US EPA, IEA GHG and VTT[3] on the work these organisations had completed on the development of "bottom up" marginal abatement cost curves (MACCs). The presentations included:

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[1] United States Environmental Protection Agency

[2] European Commission - Environment Directorate DG X1

[3] Finnish Technical Research Centre

- EC Sector Objectives Study - Agriculture and Waste, Ann Howarth, AEA Technology Ltd

- EC Sector Objectives Study - Energy Related Methane and N_2O Emissions, David de Jaeger, Ecofys b.v.

- Abatement of Emissions of Methane and Nitrous Oxide, John Gale, IEA GHG

- US Methane and N_2O Emissions and International Comparisons, Francisco de La Chesnaye, US EPA

- EC Sector Objectives Study - Fluorinated Gases, Jochen Harnisch, Ecofys b.v.

- US High Global Warming Gases, Sally Rand, US EPA

- Abatement of Emissions of the Engineered Chemicals, Jochen Harnisch, Ecofys b.v. (IEA GHG study)

- Abatement of emissions of HFCs, PFCs and SF_6- a Finnish perspective, Sami Tuhkanen, VTT

The papers allowed a detailed comparison of the methodologies applied by each of the organisations in the development of their marginal abatement cost curves to be undertaken (see Section 3.1).

On the morning of the second day a series of papers were presented that dealt with how Non-CO_2 gases cost curve data had been utilised to date in the development of "top down" economic models. The papers presented included:

- What are the gains from a multi-gas strategy? Jesper Jensen, Copenhagen Economics

- An alternative approach to establishing trade-offs between greenhouse gases, Rich Richels, EPRI

- Incorporating Non-CO_2 GHGs into the SGM[4] framework, Francisco de la Chesnaye, US EPA

- Implementation of Non-CO_2 greenhouse Gases in the MIT-EPPA Model, Jochen Harnisch, Ecofys b.v. and Francisco de la Chesnaye, US EPA

- Comprehensive GHG modeling in the Agricultural and Forestry Sectors, Bruce McCarl, Texas A&M University

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[4] Single Gas Model

Copies of all the presentational material and supporting papers provided are given in Appendix 2.

The workshop succeeded in establishing how the "top down" models had applied some of the cost curve data that was available now (See Section 3.2). The modelers indicated that more data was required and it was agreed that an action would be taken by the US EPA (on behalf of the Network) to identify the best methodology for providing the cost data.

On the final afternoon, the participants were given an opportunity to discuss plans for the future of the Non-CO_2 Greenhouse Gases Network. The purpose of this part of the meeting was:

- to decide whether there was sufficient interest in such a network and its general aims
- to decide on the organisation of the network and frequency of future meetings
- to decide the technical requirements and structure of future meetings
- to consider inviting other organisations to participate in the network's activities.

3. WORKSHOP RESULTS

3.1 Marginal abatement cost curves

3.1.1 Review of marginal abatement cost curves

The marginal abatement cost curves (MACCs) completed by US EPA, EC DG Env. and IEA GHG are compared in Table 1 overleaf. The key aspects of the MACCs are discussed below.

Technology

Various different approaches have been employed in the construction of the MACCs. For example, as far as the technology is concerned, the MACCs developed by US EPA are based on actual US emissions inventory data and the technologies used are those that industry is deploying currently in the USA. Future emissions projections are based on actual emissions data multiplied by an activity factor. Generally, no novel technology is introduced into the future projections. An activity factor is introduced based on technology implementation underway in that sector; its value is agreed with industry. As the projections are currently only undertaken to 2010[5], this is a technically sound approach. The US EPA works closely with industry in certain sectors, such as the semi-conductor industry. In many cases voluntary emissions reduction programmes have been put in place. Under the voluntary programmes, the least cost technology options are likely to be implemented first. Such agreed voluntary reductions are not included in the projected emissions reductions and so are excluded from the MACCs for certain gases in particular industry sectors. Marginal abatement cost curves, therefore, will tend to show less potential for low cost abatement than is actually the case in some sectors.

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[5] US EPA is presently extending their abatement curves projections until 2050 using the Second Generation Model developed by Pacific Northwest National Laboratory. The results of this work will be available in late 2002. It is noted that no new abatement technologies are introduced into these MACCs

Organisation	**USEPA**	**IEA GHG**	**EC**
Technology			
Technology Status	Current technology with projections based on industry consultation	Current & Predicted	Current & some predicted technology with near term deployment potential
Spread	US initially Now developed for other countries e.g. China, Russia etc.,	Global & Regional	EU and individual EU countries
Baseline data	USEPA Emissions inventory for US (1990-2000)	Averaged emissions data from sources such as USEPA, EC etc.,	EU emissions data
Prepared by	USEPA	Consultants	Consultants
Cost Data			
Tax Rate	40%	not used	not used
Discount Rates	8% typically Varies from 8 to 20% for different industries	10%	4% typically (can vary from 2-6%)
Cost data	Variable - allows input of current natural gas and electricity prices in US	Fixed	Fixed - various data sources used
Net Present Value	not presented	not presented	not presented
Data Presentation			
Data Format	Industry sectors - all gases	Gases and industry sectors	Gases in sectors
Presentation Format	\$/tCE abated versus MM[6] tCE[7] abated	\$/t CH_4 & N_2O[8] abated & \$/t/CO_2-E versus % of emissions abated	€/t CO_2-eq versus Mt/CO_2-eq abated
Currency	\$ (1995)	\$ (1995-1999)[9]	€ (1990)
Projections	Currently up to 2010	Up to 2020	Up to 2010

Table 1 Comparison of "Bottom Up" Marginal Abatement Cost Curves

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[6] MM stands for million in US convention

[7] Million tons of Carbon equivalent (metric tons)

[8] Million tons of CH_4 and N_2O abated

[9] A number of studies have been undertaken to date which have used different time points for the cost calculations. A new study is to be undertaken to harmonise the cost data to $ 2000.

In contrast, the technology based MACCs developed for IEA GHG can include more novel technology, especially as projections are made until 2020. The mitigation technology options are reviewed, their technical potential assessed up to 2020 and the consultant then uses their expertise to reach a judgment about the degree of implementation likely up to 2020.

For the EC the effort is focused on achieving the Kyoto emission reduction targets so the cost curves would be used to develop EU emission reduction strategies. The technologies included are those that the consultants (using their expert judgment) consider will be introduced in the period up to 2010. In both the IEA GHG and EC cases, there are no exclusions from the MACCs; therefore, all the low cost abatement opportunities will be presented.

Emissions and baselines

The baseline data used in the US EPA MACCs is based on actual national emissions data. US EPA has been active in developing baseline emissions data for a number of developing countries and has used this data and a technology assessment process to adapt their abatement cost curves to a number of different countries and regions. Countries included in this exercise are China, India, Ukraine, Brazil, Mexico, Russia, Japan and Canada. A similar approach has been used for Europe and Australia/New Zealand. Technology introduction has been adapted in each case based on US EPA's expert judgment of the situation in each country and which mitigation options are most applicable in that country. For Europe, the US EPA has used the EC Sectoral Study data.

The EC's MACCs are based on national inventory data from the EC databases and provides a European cost curve, as well as cost curve data for individual EU countries.

IEA GHG on the other hand provides global cost curve data, and except in the case of methane, regional cost curve data as well, although, due to data limitations, different global regions were selected to develop MACC curves for the N_2O and High GWP gases studies. Data on emissions for the IEA GHG studies come from a number of sources including US EPA and EC data.

Cost information

The cost basis for the MACCs is also different in most cases. For instance, US EPA includes 40% tax[10] in their calculations whilst neither IEA GHG and EC do not introduce tax into their assessments. IEA GHG uses a discount rate of 10% with sensitivity at 5%; the EC work uses a rate of 4% and undertakes sensitivity analyses at 2% and 6%. The US EPA uses a variable discount rate for different industry sectors; this can vary between 8 and 20%. Higher discount rates are used for the more capital-intensive industries like iron and steel manufacturing[11]. The use of lower discount rates will tend to favour higher

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[10] The 40% tax is the US corporate/business tax on income or revenue.

[11] US EPA uses different discount rates for different industry sectors, because their analyses are used to set emission reduction targets for voluntary programs with various industry sectors. It is, therefore,

capital cost systems. IEA GHG uses a set of standard assessment criteria, to ensure its studies are carried out on a consistent basis which include, for example, particular energy prices and project lifetime assumptions (typically 25 years for large projects such as power plant construction, but can be shorter for example for retrofit projects). The EC studies include agreed cost criteria based on EC data sources; project lifetimes (10-25 years) vary depending on the technology concerned. The US EPA MACCs allow the energy price data to be adjusted to meet changing circumstances i.e. energy price variations. In this case changes in energy prices can be analysed as sensitivity studies.

MACC presentation

The cost curves are also presented very differently. US EPA expresses it results in US dollars per tons of Carbon Equivalent[12], the EC uses Euro per tonne of CO_2-equivalent[13], whilst IEA GHG uses US dollars per tonne of gas (CH_4 and N_2O) and has recently added US $ per tonne of CO_2-equivalent (based on the 100year GWP).

There is also a difference in view as to whether the curves are truly representing marginal costs. In theory, the curves should be constructed by identifying the next unit of marginal capacity available and the cost increment associated with it. In the case of US EPA data rather than model the next unit of marginal capacity available within every company, e.g. every landfill and coalmine, the analysis accounts for the next marginal reduction unit, based on representative size, in an industrial sector. The IEA GHG and EC data is only an approximation to marginal costs, identifying significant amounts of emission reduction arising from introduction of a particular unit of technology, and assigning the same cost per unit to each. In a more detailed exercise, this restriction could be lifted.

Overall, it is apparent that it is very difficult to compare directly the MACCs presented by the different organisations undertaking such work because of the different way that they have been constructed.

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considered appropriate to use industry- specific discount rates. In addition, the analyses are all submitted to industry (companies, associations, etc) for peer review which also necessitated using familiar, accepted cost factors.

[12] Data is corrected based on the different 100 year GWPs for the gases to a CO_2 equivalent and then recalculated to a mass of Carbon based on the ratio of molecular weights of carbon and CO_2.

[13] CO_2 Equivalent - this weights each gas by its GWP (100 year time horizon) which indicate how unit mass of each gas enhances radiative forcing compared to CO_2, taking into account their different lifetimes in the atmosphere.

3.1.2 Conclusion from MACC review

The main conclusions that can be drawn from the review of the various marginal abatement curves presented are as follows:

1. Technology based MACC data have been developed by the US EPA, EC and IEA GHG. The approach used in the development of these "bottom up" cost curves differs significantly and caution should be exercised in comparing directly the data provided. The different approaches used in part reflect the differing reasons for cost curve preparation. For the EC, the curves are designed to act as policy guidance instruments to allow the EC to meet its Kyoto targets, hence they forecast no later than 2010. US EPA curves are also used for policy guidance and also focus on 2010. In contrast, IEA GHG curves are designed to provide more general information to its members and include information on implementation to 2020. Thus more novel technology is included in the IEA GHG cost curves than in those for the US EPA and EC. The US EPA prepares their own MACC data with close participation/involvement with industry and, hence, agreed voluntary reductions are excluded. The low cost options can, therefore, appear more limited in extent in the US EPA MACCs, since these measures are the ones industry will go for first in any voluntary reduction programme. IEA GHG and the EC curves are prepared by external consultants and therefore rely more on the expert judgment of different individuals.

2. The cost data used in the construction of these curves also differ, as does the presentational form. To allow more direct comparison it could be worth attempting to standardise on the presentational format i.e. all use CO_2-equivalent or prepare step off cases in different formats and with sensitivity studies on tax and discount rates undertaken to reflect the range of values used in the other studies

3. Technology based MACC data has been developed by the US EPA, EC and IEA GHG. The approach used in the development of these "bottom up" cost curves differs significantly and caution should be exercised in comparing directly the data provided. The different approaches used in part reflect the differing reasons for cost curve preparation. For the EC, the curves are designed to act as policy guidance instruments to allow the EC to meet its Kyoto targets, hence they forecast no later than 2010. US EPA curves are also used for policy guidance and also focus on 2010. In contrast, IEA GHG curves are designed to provide its members with information of more general applicability – it includes information for implementation to 2020. Thus more novel technology is included in the IEA GHG cost curves than in those for the US EPA and EC. The US EPA prepares their own MACC data with close participation/involvement with industry and, hence, agreed voluntary reductions are excluded. The low cost options can, therefore, appear more limited in extent in the US EPA MACCs, since these measures are the ones industry will go for first in any voluntary reduction programme. IEA GHG and the EC curves are prepared by external consultants and therefore rely more on the expert judgment of different individuals.

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3.2 Non-CO_2 Gases in "Top Down" Economic Models

3.2.1 Review of treatment of Non-CO_2 GHGs in different economic models

The approach used to include the Non-CO_2 greenhouse gases in a number of different economic models has been compared. The models discussed are outlined in the Table 2 overleaf:

Model	**Developer**
EDGE	Copenhagen School of Economics
MERGE	Electrical Power Research Institute (EPRI)/Stanford University
EPPA	Massachusetts Institute of Technology (MIT)
SGM	Pacific Northwest National Laboratory (PNNL)

Table 2 Summary of Economic Models Reviewed During Workshop

The EDGE model is a dynamic equilibrium model that is using a multi-gas approach for estimating the marginal abatement cost curves for the EU. It is a global model with 8 regions and incorporates 7 production sectors (5 energy sectors) and uses a Ramsey[14] type representative agent to extrapolate data to 2030. The model uses emissions information from UNFCC[15] national inventory data and uses "bottom up" technology based MACC data (from EC and US EPA) to estimate economy-wide MACCs for the EU and US. Cost curves are presented as aggregate curves for Non-CO_2 gases (100 year GWP), for CO_2 and for a multi-gas approach to meeting EU targets. The model assumes compliance with Kyoto targets, no revenue recycling and unlimited Annex B emissions trading. The output from the model indicates that the multi-gas approach represents the least cost strategy to reduce emissions. The MACCs exclude any negative cost technology data; any currently cost-effective options cannot be handled by the model and are thus excluded from the model inputs. As noted earlier, US EPA data relates to currently deployed technology, extrapolating this data to 2030 therefore excludes technology that could be expected to be introduced and therefore may underestimate potential emission reductions.

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[14] A Ramsey agent makes explicit assumptions about current consumption versus future welfare.

[15] United Nations Framework Convention On Climate Change

The MERGE 4.0 model is a general equilibrium model, which uses a "bottom up" technology approach to model the energy sectors and allows a choice of the number of technologies that can be used. For the economic modeling it uses a "top down" approach. For data extrapolation, a standard Ramsey type function is again used. The model was originally constructed for CO_2 but has now been extended to include CH_4 and N_2O (100 year GWP data used). The inclusion of these gases places constraints on the energy sector because the choice of technology is influenced by their CO_2 and CH_4 emissions. The technology MACC curve data was obtained from MIT (source US EPA data). The high GWP gases are not included but the cooling effect of sulphur aerosols is. The data is projected for 100 hundred years (i.e. to 2200) for USA alone. The results indicate that, considering CO_2 alone, 66% of US emission reductions would come from US domestic measures, the rest from emissions trading. If the Non-CO_2 gases are included, the model shows that the price of carbon drops and more credits can be bought, thereby reducing the need for US domestic reductions.

The MIT EPPA model has been developed in two stages. Until late 1999 the model was based on US EPA MACC data for the USA alone. The gases included were CO_2, CH_4, N_2O, PFCs, HFCs and SF_6. The information input was based on emissions data available at the time - in some cases, like HFCs, some emissions sources were not included where data was limited. Marginal abatement cost curves for the USA was developed for 2010 for multi gas control to model achievement of the Kyoto targets. The US EPA MACC data was then extrapolated to other regions. The method used varied for the different gases. For PFCs and HFCs, the data was extrapolated based on GDP alone; for methane, a number of factors were used including agricultural, natural gas and coal production and estimates for biomass burning from deforestation. Cost curves were then prepared for a number of regions that included Japan, EU, and Former Soviet Union. These curves assume that US mitigation/technology options can be extrapolated to other regions by the use of appropriate economic indicators. For comparison, data from an EC study was input; this showed that there were significant variations between the US extrapolated data and actual regional data. It was considered that the approach used was not the best available and the incorporation of the newer US EPA data on regional technology introduction and emissions would give better results.

Recently, the EPPA model has been modified to include more information on CH_4 sources and emissions based on US EPA and IEA GHG data. The model has been used to develop MACC data for CH_4 abatement in countries such as US, China, India, Brazil and Japan. Reasonable agreement between the model output and the US EPA and IEA GHG cost curve data for methane alone has been achieved. The results have shown that, in developing countries, methane could play a significant role in reducing overall greenhouse gas emissions reduction.

Pacific Northwest National Laboratory has developed the Second Generation Model or SGM in collaboration with the US EPA. The 2000 version of the model includes 22 production sectors and 14 world regions including both Annex B and Non Annex B countries. The model uses US EPA regional emissions and technology cost curve data to develop cost curves for the regions covered by the model. For certain regions aggregate

MACC curve data has been used i.e. for the EC. The approach used by SGM is to take MACCs for Non-CO_2 gases decompose them and modify the production coefficients/functions in the model to reflect the MACCs. The data is then input as reduced form equations (regressions), which allow quick and easy data substitution in the model. This contrasts with the MIT approach that uses economic indicators to adapt MACCs. To date, the model has incorporated CO_2 and CH_4 data but other gases will follow. The model has indicated for the USA that for short-term targets, CH_4 reductions can reduce costs by some 25% for meeting greenhouse gas reduction targets compared to abatement of CO_2 alone.

3.2.2 Conclusions from review of economic models

The main conclusions that can be drawn from the review of the way the Non-CO_2 greenhouse gases have been treated in the economic models reviewed are as follows:

1. A number of "top down" economic models have been developed and compared. In all cases the way the projected cost curves have been developed varies for each model. All the models use US EPA MACC curve data in some way. The MIT model has used US based MACC curve data and extrapolated this to other regions of the world using economic indicators to develop "top down" MACCs. This does not appear to have been as effective as the SGM model that has used the more recent, regionalised US EPA data and attempted to describe the cost curve data using reduced form equations rather than extrapolate using economic criteria.

2. All the economic models are at a relatively early stage in introducing Non-CO_2 gas data and not all the models include the full range of Non-CO_2 gases yet. An exercise of working with the modelers (or selected modeling group) to input technology based MACC data on the Non-CO_2 gases would be worthwhile. At the meeting the general consensus was that the modeling community is keen for such an exercise to happen.

3. Some of the economic models incorporate emissions data based on current technology and extrapolate the data to 2030 and beyond. For the most accurate forward extrapolation, details on future technology options and likely technology implementation rates are needed.

4. All of the economic models indicate that including the Non-CO_2 gases in a national/regional abatement strategy reduces abatement costs compared to targeting CO_2 reductions alone for near term reductions (up to 2010).

4. WORKSHOP CONCLUSIONS

The workshop was extremely well received and delegates were unanimous in their desire for the continuation of such a network. It was agreed that a further meeting would be held in conjunction with the Third International Symposium on Non-CO_2 Greenhouse Gases (NCGG-3) to be held in Maastricht from 21st to 23rd January 2002.

A comparison of the methodologies applied by each of the organisations in the development of their abatement cost curves has been carried out. It was agreed at the workshop that the US EPA would lead a small group that would discuss how best to present the "bottom up" cost data for application in the "top down" economic models. This exercise would be reported at the next meeting in Maastricht; other modelers whose work had not been reported in Brussels would also get the opportunity to present their work.

It was agreed that the Non-CO_2 Greenhouse Gases Network should try to extend itself to include experts and policy makers from developing countries; all participants were invited to suggest potential new delegates from these regions.

Based on the results presented at the meeting, participants recognised the agricultural sector as a major source of methane and N_2O emissions. However, it was agreed that extensive further research would be needed to acquire suitable abatement options that are both cost-effective and capable of implementation (technically, as well as socially and politically). The challenges involved in finding mitigation options in agriculture are considerable both in the industrialised and developing countries. Detailed discussion of the agricultural sector could be the focus of a network meeting in mid/late 2002.

The results presented also indicated that it was important to analyse the agricultural sector as a "farming system" where methane, N_2O and CO_2 (soil carbon) emissions are looked at in an integrated manner. It was demonstrated that in many cases if you try and reduce individual gas emissions, the emissions of other gases from soils might increase. One example is nitrous oxide reduction through manure management practices, which increases anaerobic bacterial activity creating higher methane emissions. Similarly, altering tillage practices to reduce indirect N_2O emissions can result in increased emissions of CO_2 from soils. IEA GHG already has an action from the 19th ExCo meeting (Regina) to consider all aspects of greenhouse gas emissions and sequestration in soils.

5. FOLLOW ON ACTIONS

It was proposed that IEA GHG act as the secretariat for the Network and maintains the mailing list. IEA GHG was also asked to consider establishing a webpage for the Network on the IEA GHG website to act as an information site. The site will act as a reference site for non-CO_2 Greenhouse Gas activities and provide links to organisation sites such as US EPA's where cost curve data is presented. The webpage would also provide information and linkages to modeling activities underway that are incorporating non-CO_2 gases. It was considered important that such an umbrella site linking all activities on non-CO_2 gases was needed to help catalyse co-operation in the field. IEA GHG was considered well placed to provide such an international bridge.

A short report on the meeting will be prepared jointly with the US EPA, which will be disseminated in the September Issue of the "Greenhouse Issues" newsletter. IEA GHG will prepare a more detailed report for circulation to its members.

APPENDIX 1

WORKSHOP ATTENDANCE LIST

Non-CO_2 GHGs Network Meeting

14th & 15th June 2001, European Commission, Environment Directorate-General,
5 Avenue de Beaulieu, Brussels, Belgium

Attendance List

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APPENDIX 2

COPIES OF PRESENTATION MATERIALS AND SUPPORTING PAPERS PROVIDED

Welcome

Non-CO2 greenhouse gas network
meeting 14-15 June 2001
US EPA, IEA GHG and European Commission

Objectives

- Bring together leading researchers and policy advisors
- Compare data, mitigation options, economic modelling and empirical results
- Frank and open dialogue
- Co-operation in the future
- This time, focus on mitigation technologies and cost curves

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Also need to agree where to go

- Decide the aims of the Non-CO2 network
  - eg. deepen knowledge in Annex 1 or expand the network wider
- Decide organisation and frequency of meetings
- Decide on requirements and structure of meetings
- Consider who else to invite

Programme

- Presentations of latest work on Non-CO2 gases by Commission, IEA, EPA and VTT
  - Discussion on results
- Incorporating Non-CO2 with CGE models
- Terrestrial sequestration
- Discussion of where next
  - Development of the network

Organisational issues

- ✓ Moderators keep presentations max 20 min to allow for discussion
  - Auto-criticism encouraged
- ✓ All presentations to be delivered by e-mail
  - and placed on the web?
- ✓ Each presenter should make a short (1 page) summary of discussion
  - Main findings and decisions published

Some remarks

- ✓ **In EU, effects of non-CO2 not closely looked into**
  - in recent Sectoral Objectives study, non-CO2 was placed on equal footing with CO2 in terms of coverage and importance
  - found cheap options but also uncertainties in data
- ✓ **Knowledge of non-CO2 in developing countries seems much scantier**
- ✓ **Non-CO2 network crucial to help carry EU's work (incl. economics of sinks) further**
  - believe that the role is similar to other network participants
- ✓ **Concentrate on unravelling new knowledge**
  - leave climate politics and negotiations to Bonn

Non-CO_2 GHG Network: Concept & Opportunities

Dina Kruger
Chief, Methane & Sequestration Branch
US Environmental Protection Agency

June 14, 2001

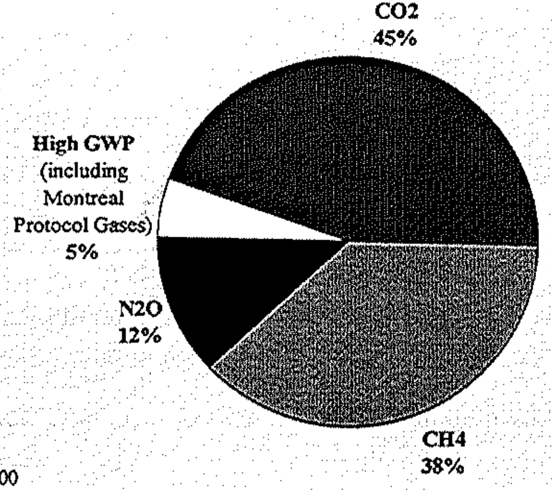
Overview

- Role of Non-CO_2 Greenhouse Gases
- Key Challenges
- Opportunities for the Network

Role of Non-CO_2 GHGs

- Climatic Importance
- Economic Benefits
- Technological Opportunities

Non-CO_2 Gases are Important



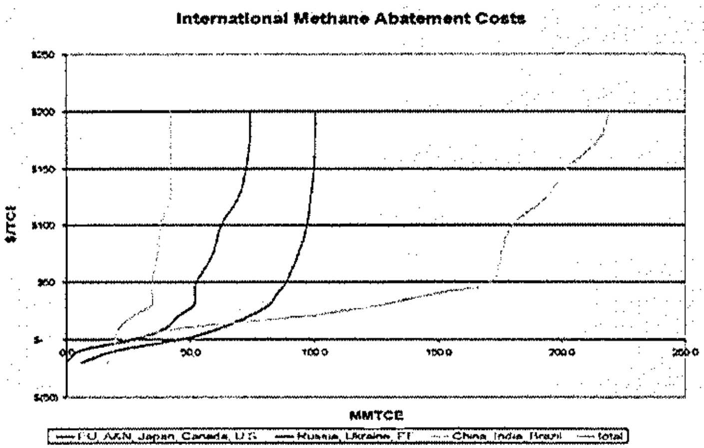
Source: SRES, 2000

Non-CO_2 Gases Needed for Climate Protection

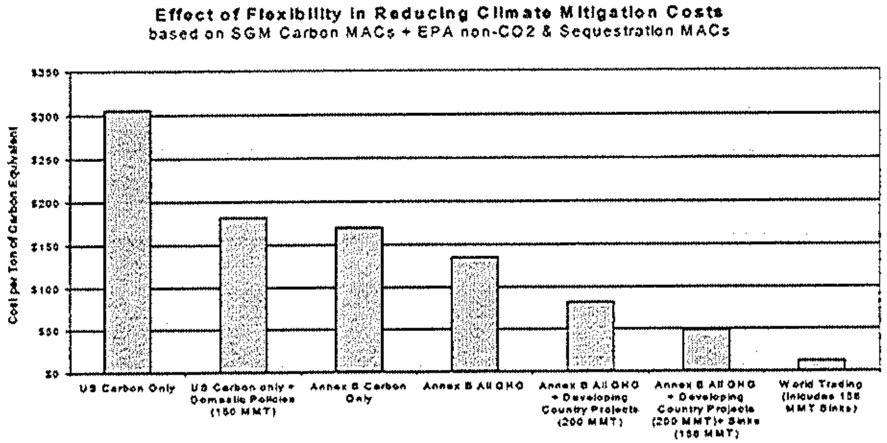
- In 2100, Non-CO_2 GHGs contribute 25-40% of radiative forcing
- If aim was 550 ppm-CO_2 concentration…
  - uncontrolled Non-CO_2 GHGs could add 100-200 ppm

  - Smith, 2001; based on SRES

Many Cost-effective Opportunities to Reduce Non-CO_2 GHGs


International Methane Abatement Costs

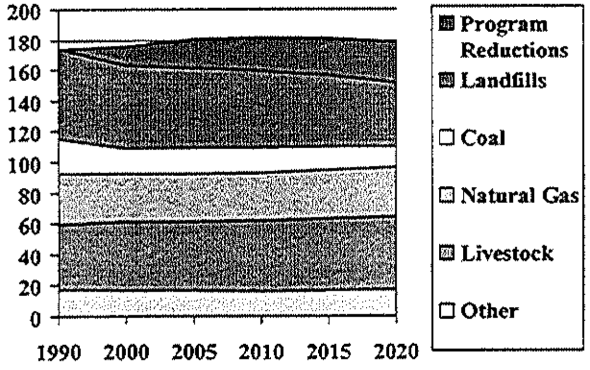
Including Non-CO_2 GHGs in Lowers Costs


Effect of Flexibility in Reducing Climate Mitigation Costs
based on SGM Carbon MACs + EPA non-CO2 & Sequestration MACs

Many Technologies Available to Reduce Emissions

- Opportunities across almost all sources & industries
- Multiple benefits (I.e., safety, energy supply, improved efficiency, air quality)
- Many options are economically attractive at current energy prices

Impact of Voluntary Programs on US Non-CO_2 Emissions



Variety of Policy Approaches for Non-CO_2 GHGs

- Voluntary industry partnerships and programs
- Fiscal incentives
- Market-based programs
  - allowance based trade
  - credit-based trading
- Regulatory Actions

Key Challenges

- Economic Modeling
- Technology Deployment
- Policy Development
- Scientific Understanding

Economic Modeling Challenges

- Developing basic economic data that reflects sectoral and national differences
- Providing enough transparency to ensure different studies are comparable
- Integrating Non-CO_2 GHGs into macro-models

Technology Deployment Challenges

- Identifying full range of mitigation possibilities, particularly for newer emission sources
- Understanding the cost & performance characteristics of technologies
- Addressing barriers to deployment
- Anticipating the evolution of technologies

Policy Development Challenges

- Identifying the range of policy options available
- Ensuring the unique characteristics of emissions sources/sectors are reflected in policy choices

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Scientific Challenges

- Long-range emission projections
- Atmospheric interactions
- Metrics for comparing emissions and reductions of different GHGs
- Understanding the roles that GHGs with different characteristics can play in climate mitigation

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Opportunities for the Network

- Economic Modeling
  - Exchange data and information
  - Build community of economists working on these issues
- Technology Deployment
  - Identify what technologies are available
  - Share information on technology characteristics, barriers to deployment

Opportunities for the Network

- Policy Analysis
  - What policies are in use or under consideration?
  - How do various policies work in particular sectors?

Opportunities for the Network

- Scientific Issues
  - Emission projections: what are the key drivers of non-CO_2 emissions, by sector?
  - Equivalence metrics: What alternative metrics for GHGs are under consideration & what issues do they address?
  - Climate mitigation: How do various non-CO_2 GHG reductions effect climate change in the near-term and the long-term?

Conclusions

- Non-CO_2 GHGs are too important to ignore
- Given the nature of the sources, specialized expertise and focused attention is required
- To date, opportunities to exchange among experts across sectors & countries have been limited
- Many countries are developing non-CO_2 GHG expertise

Network will serve a Key Role

- Connecting experts
- Challenging us all to do better analyses
- Providing us with new ideas and informed feedback
- Creating a foundation to address -- comprehensively -- the challenge of global climate change

EC Sectoral Objectives Study - Waste and Agriculture

Ann Haworth

Overview

- Waste
  - Emissions
  - Options - remarks on feedback and applicability
  - Baseline trends and aggregation of options
- Agriculture
  - Emissions
  - Options - remarks on feedback and applicability
  - Baseline trends and aggregation of options

Waste - Emissions

- Methane emissions from landfill represent 4% of EU emissions in 1990 but 34% of methane emissions

- Between 1995 and 1990, there was a 22% reduction due to measures in Member States

Waste - Options

- Reduction of waste arisings
- Diversion of biodegradable waste away from landfill
  - Composting
  - MBT
  - Anaerobic digestion
  - Recycling of paper
- Collection and combustion of landfill gas
- Improved oxidation in landfill cap

Cost effectiveness of waste diversion options

- Paper recycling, incineration and anaerobic digestion cost effective (dependent on pollution controls required)
- Composting and MBT not cost effective

Comments

- Much discussion over relative merits/costs of incineration and composting
- Discount rate used tends to favour high capital cost systems
- DG Env Detailed study on ghg from waste - dependent on detailed assumptions - composting good but not necessarily best in terms of greenhouse gases
- Applicability elsewhere?

Other options

- Flaring of landfill gas (not cost effective but relatively low cost)
- Electricity and heat generation from landfill gas (cost effective)
- Production of synthetic natural gas (cost effective but limited to landfills close to a gas pipeline)
- Improved oxidation through capping (not cost effective)

Projections and aggregation of options in the waste sector

- Baseline (including landfill directive) - 28% compared to 1990
- Additional low cost reductions of 18 MtCO2
- Most cost effective measures - paper recycling, heat or electricity production from landfill gas, production of synthetic natural gas
- In context of whole study, least cost allocation to waste -13%

Agriculture emissions

- Agriculture accounted for 11% of EU emissions in 1990 but 51% of N_2O and 41% CH_4
- Three mechanisms
  - methane from enteric fermentation
  - methane and nitrous oxide from manure
  - nitrous oxide from soils
- Not considered social changes such as reduction in demand

Enteric fermentation - Options

- Improve feed conversion efficiency
  - Improved genetics
  - Replacing roughage with concentrates
  - Including non structural carbohydrates in concentrate
  - High fat diet
- Increase animal productivity through food additives
- Improve rumen efficiency
  - Hexose partitioning
  - Propionate precursors
  - Direct fed microbials
  - Genetic approach
  - Immunogenic approach

Comments

- Feed conversion options cost effective (increased productivity) but applicability limited in EU
- Most of options for rumen efficiency unacceptable to public. (Except propionate precursors)
- Robust demonstration of long term benefits or problems (health) from these options is lacking
- Options lead to intensification of agriculture

Options on manure management

- Main strategy to use manure management to
  - ensure aerobic decomposition
  - use controlled anaerobic digestion to collect methane to burn to convert to carbon dioxide (also reduces potential N_2O emissions)
    - Pig slurry management
    - Controlled anaerobic digestion
    - Daily spreading
    - Composting and aerobic treatments

Comments

- Pig slurry management not cost effective but likely to be implemented for other reasons
- Anaerobic digestion - cost effectiveness dependent on electricity and heat generation
- Daily spreading and composting likely to increase other emissions

Options for soil management

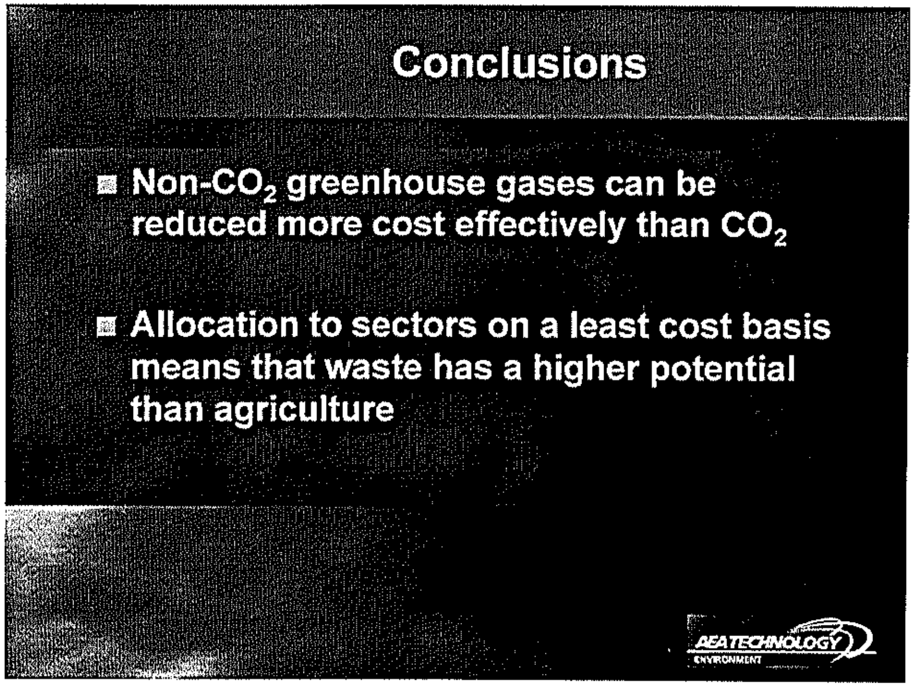
- Improve efficiency of fertiliser use
  - Managing fallow periods
  - Matching fertiliser type to season
  - Multiple applications of fertiliser
  - Slow or controlled release fertiliser
  - N-transformation inhibitors
  - Rewetting of farmed organic soils
- Optimising N application
  - Improved maintenance of fertiliser spreaders
  - Optimisation of fertiliser distribution geometry
  - Precision farming
  - allowing for residual N
- Continuation of set aside

Comments

- All options cost effective (from reduction in fertiliser use)
- <u>But</u> - big barrier is risk (real or perceived) of losing yield
- In current economic climate widespread implementation unlikely
- Could be encouraged - sometimes other benefits (improved spreader maintenance)

Projections and aggregation of options

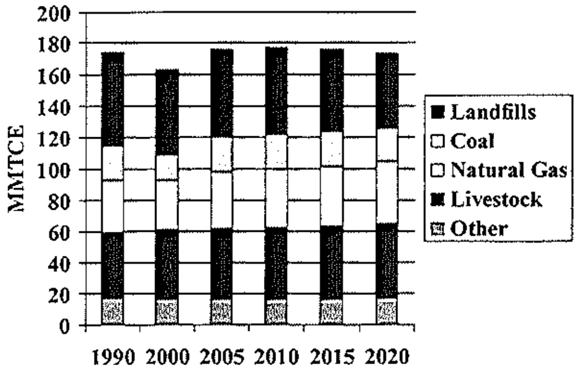
- Baseline -8% compared to 1990 due to falling livestock numbers
- Additional low cost options -4%
- Social trends in agriculture may act to increase greenhouse gas emissions



Conclusions

- Non-CO_2 greenhouse gases can be reduced more cost effectively than CO_2
- Allocation to sectors on a least cost basis means that waste has a higher potential than agriculture

Emission Profile for Methane in the U.S.



Cost Analysis by Sector

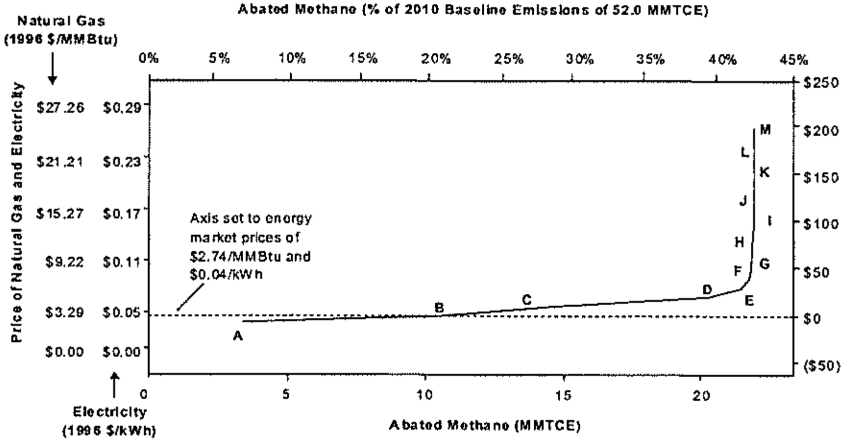
- Identify emission reduction technologies/practices Including:
  - – capital and O&M costs
  - – economic life of the project
  - – achievable savings (GHG reductions) from each technology/practice
- Solve for carbon-equivalent price for the savings that yield an NPV of $0 at selected industry specific discount rate and a tax rate of 40%

Available Abatement Technologies

Source	**Key Technologies**
Landfills	Methane recovery, combustion (power generation, industrial uses, flaring)
Coal Mines	Methane recovery through wells (combustion and flaring), ventilation air methane (flaring)
Gas/Oil Systems	Use of low-bleed equipment, better management practices (inspection and maintenance)
Manure Management	Methane collection from anaerobic digesters and combustion (power, flaring)

Marginal Abatement Curve for Methane Emissions from Landfills in 2010

Source: EPA, 1999



U.S. Methane and Nitrous Oxide Cost Analysis

Casey Delhotal, Economist
Methane & Sequestration Branch
U.S. Environmental Protection Agency

Overview

- Methane reduction estimates
  - Domestic and International Analysis
- Nitrous Oxide reduction estimates
  - Adipic and Nitric Acid Industry
- Next Steps

Future Baseline Emissions are the Starting Point for the Cost Analysis

- Baselines:
  - do not include Climate Change Action Plan (CCAP) activities
  - do not include effects of regulations (ex. Landfill Rule, MSHA safety rules)
  - developed using recent detailed emission inventories and projections of emissions and activity factors

Future Emission Estimates

- Based on source-specific emission and activity factors
  - Example: Natural Gas Emission = $\Sigma(EF \times AF)$ where EF are emission factors and AF are activity factors
- Use industry/source activity factor drivers for updating annual estimate
  - Example: natural gas production for emissions from transmission and production of natural gas
- Adjust emission factors for technology change and equipment turnover
  - assumed only in the natural gas sector

Predicted Impact

Abatement Measure	N_2O Abated Mt/y	% of Global N_2O Emissions
Industrial		
Nitric acid measures	*0.58*	*4.2*
Adipic acid measures	*0.21*	*1.5*
Total Industrial	0.79	5.7
Total Agricultural	0.16	1.1
TOTAL	0.95	6.8

Conclusions - N_2O Emissions

Summary

- Agricultural sector is largest single source
  - Many abatement options identified
  - Options not field tested
  - Costs and impact uncertain
- Industrial sector significant source of emissions
  - Several measures to reduce industrial emissions
  - Implementation likely to have only limited impact

N_2O Abatement Costs

Agricultural Sector

Abatement Measure	Costs $/t N_2O abated
Soil testing	-1 500
Controlled release fertilisers	15 200
Nitrification inhibitors	20 800
Manure substitution	74 300

Abatement of N_2O Emissions

Industrial Sector

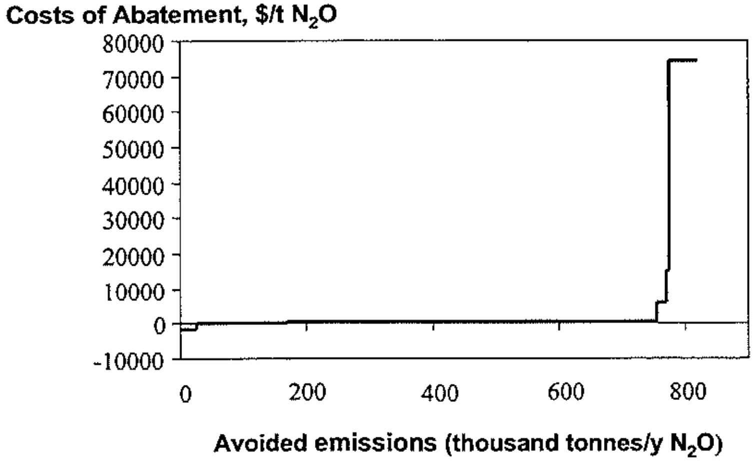
Abatement Measure	Potential Abatement (%)	Status
Adipic Acid		
Catalytic destruction	95	Commercial
Thermal destruction	98	Commercial
Nitric Acid		
NSCR	85	Commercial
Catalytic destruction	80	Development

N_2O Abatement Costs

Industrial Sector

Abatement Measure	Costs $/t N_2O abated
Adipic Acid	
Catalytic Destruction	20-60
Thermal Destruction	45
Nitric Acid	
NSCR	754

N_2O Abatement Costs

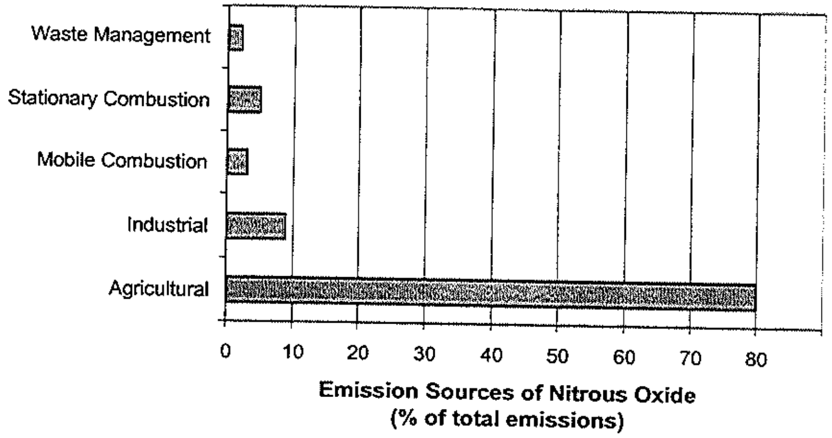


N_2O

Contribution to Climate Change

- N_2O global warming potential = 310 (100 year)
- Global average concentration in atmosphere:
  - ➢ Pre-industrial times 275 ppb
  - ➢ 1992 311 ppb
- Global anthropogenic emissions
  - ➢ 1900 2.7 Mt/y
  - ➢ 1990 12.6 Mt/y
- Considerable uncertainty in emission estimates

N_2O Emission Sources



N_2O Emission Sources

Agricultural Sector

- N_2O naturally produced in soils by nitrification and de-nitrification processes
- Principal sources
  - ➢ Emissions from soils due to nitrogen application - 56%
  - ➢ Indirect emissions from fertiliser volatilisation and from run-off water - 33%

Industrial Sector

- Adipic and Nitric acid manufacture

Abatement of N_2O Emissions

Agricultural Sector

- Improved efficiency of fertiliser use
  - ➢ Altering the timing/frequency of fertiliser application
  - ➢ Controlled-release fertilisers
  - ➢ Field testing to reduce excessive application
  - ➢ Controls direct and indirect emissions
- Methods to reduce biogenic production of CO_2
  - ➢ Nitrification and urease inhibitors
  - ➢ Altering depth of nitrogen injection
  - ➢ Site specific irrigation
  - ➢ Controls direct emissions only

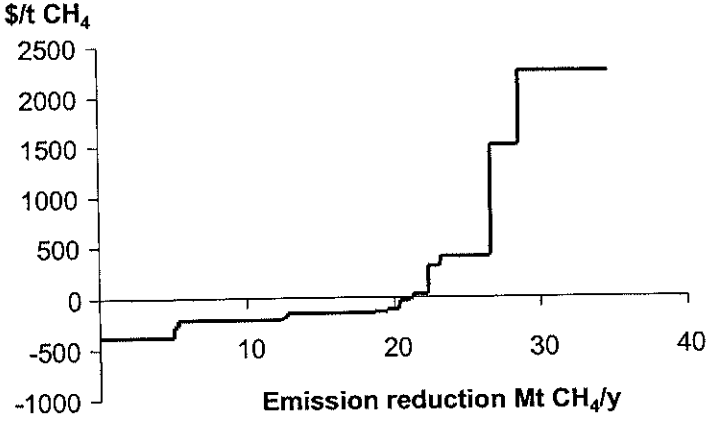
Abatement Costs

Oil and Gas Sector

Abatement Option	Abatement Costs, $/t CH_4 abated
Associated gas	-2000 to +400
Compressors	-215 to +35
Pneumatic devices	-375
Distribution leaks	-270 to +2235
Vents, maintenance & Exploration	-190 to +500

Abatement costs

Methane abatement - oil and gas sector



Conclusions - CH_4 Abatement

Oil and Gas Sector

- Cost effective to avoid 45% of emissions now
- Investment needed ~ $8 billion with annual savings of ~ $5 billion per year
- 70% of emissions could be avoided by technology that is readily available
- By 2010 this would rise to 80%
- Investment needed would be $200 to 300 billion

Abatement Cost Curves

Technology Based

- Include currently available and future technology options
- Based on technology implementation now and up to 2020
- These cost curves are global (not regional)
- Costs based on available data
  - ➢ Over project lifetime
  - ➢ 5% or 10% discount rate

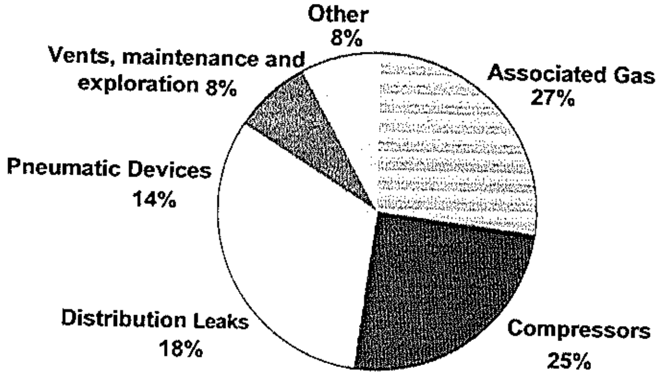
Abatement of CH_4 Emissions

Oil and Gas Sector

- Emissions arise at all stages of production and use
- Current emissions 47 Mt/y (1992)
- Gas industry ~73% of emissions, oil industry ~ 27%
- Russia ~ 53% of emissions at time of study
- Most emissions arise in gas transportation system
- Projected to rise to 78 Mt/y by 2025
- Rise due to increased natural gas production and greater pipeline distances.

Emissions Sources

Oil and Gas Sector



Abatement of CH_4 Emissions

Emission Source	***Abatement Option***
• Associated gas	Reinjection
	Flaring
• Compressors	Capture and reuse of flushing gas
	Improved seal design
	Replacement
	Improved inspection and maintenance
• Pneumatic devices	Replacement

Abatement Potential

Oil and Gas Sector

Abatement Option	Technical Potential %	Emission Reduction, Mt/y
Associated gas	50	6.3
Compressors	80	9.4
Pneumatic devices	75	4.9
Distribution leaks	50	4.2
Vents, maintenance & Exploration	50	1.7
TOTAL	***73***	***26.5***

Abatement of Methane and Nitrous Oxide Emissions

John Gale

IEA Greenhouse Gas R&D Programme

Non CO_2 Greenhouse Gases Network Meeting
Brussels, 14-15th June 2001

www.ieagreen.org.uk

Abatement of Emissions

Introduction

- IEA GHG abatement studies include CH_4 and N_2O as well as CO_2
- Abatement cost curves - a CH_4 example will show how these were developed
- Outline of IEA GHG results on abatement of N_2O emissions

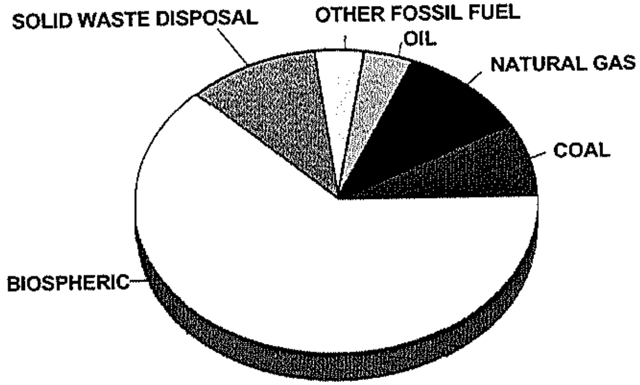
Abatement Cost Curves

Process of Development

- Identify emission sources
- Identify technology options available to reduce emissions
- Determine technical potential for emissions reduction
- Determine cost and savings over project lifetime
- Develop abatement cost curve

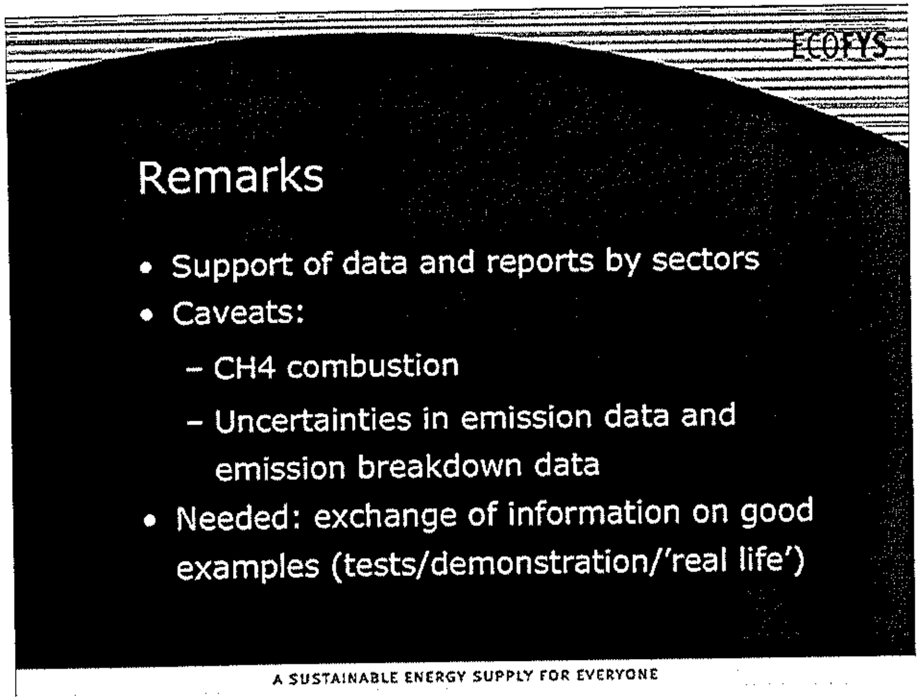
Sources of Methane Emissions

Anthropogenic



Global anthropogenic emissions = 375Mt/y

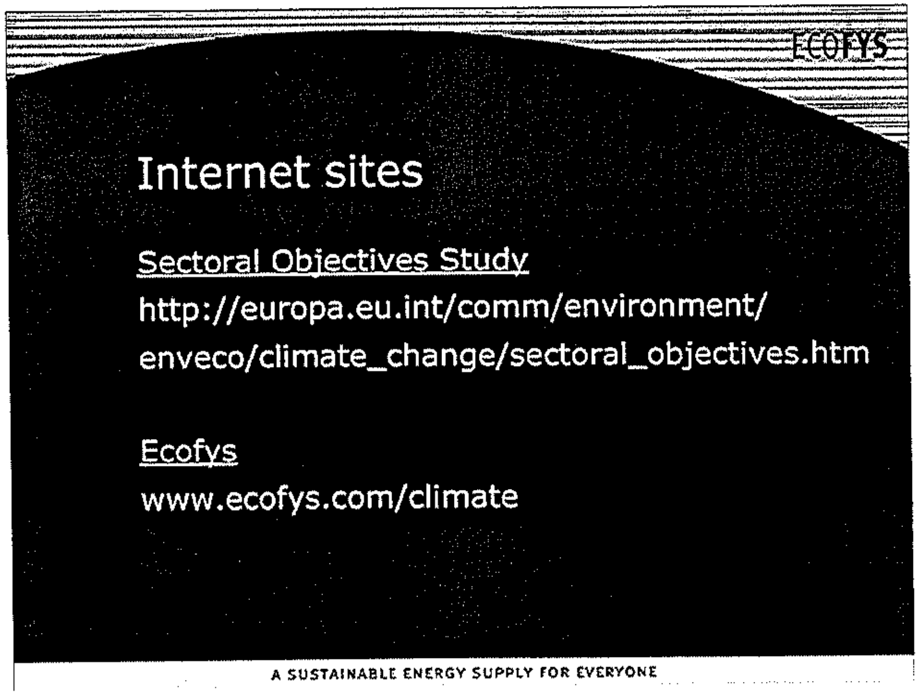
Natural sources = 160Mt/y



ECOFYS

Remarks

- Support of data and reports by sectors
- Caveats:
  - – CH4 combustion
  - – Uncertainties in emission data and emission breakdown data
- Needed: exchange of information on good examples (tests/demonstration/'real life')



ECOFYS

Internet sites

Sectoral Objectives Study

http://europa.eu.int/comm/environment/enveco/climate_change/sectoral_objectives.htm

Ecofys

www.ecofys.com/climate

CH4 - oil and natural gas (2)

Example: Associated gas (3% of total emissions)

- recovery and utilisation (EOR)
  - on-site energy production
  - LNG production
- flaring instead of venting
- improved flare efficiencies

- Emission reduction: 0.6 Mt CO_2-eq. (>95%)
- Reduction costs: -4 to 4 Euro/tCO_2-eq.

CH4 - oil and natural gas (3)

Example: compressor stations (3%)

- hydraulically powered valve actuators
- relocating of valves
- minimising number of changeovers
- recompression during maintenance
- reduced flushing
- flaring of seal losses
- improved sealing of compressors
- electrical start-up

- Emission reduction: 0.4 Mt CO_2-eq. (20%)
- Reduction costs: -4 (to 76) Euro/tCO_2-eq.

CH4 - oil and natural gas (4)

Fugitive emissions (75%-80%)

- Transport and distribution
  - replacement of grey cast-iron network
  - increasing pipeline examination frequency
  - recompression during pipeline maintenance
- Other parts of the fuel chain
- Emission reduction: 20 Mt CO_2-eq. (60-70%)
- Reduction costs: 40 to 80 Euro/tCO_2-eq.

Results

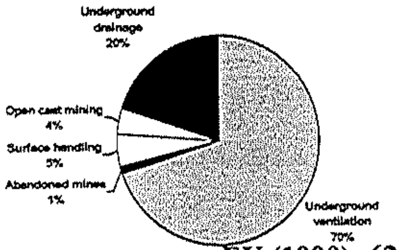
- Total energy NCGG emissions: 105 Mt CO_2-eq.
- Technical reduction potential: 37 Mt CO_2-eq.

o.w. <0 Euro/tCO_2: 9 Mt CO_2
0-20 Euro/tCO_2: 4 Mt CO_2

- Largest reductions:
  - natural gas distribution (25 Mt, >40 Euro/tCO_2)
  - coal mining (9 Mt, < 2 Euro/tCO_2)
  - N_2O FBC (2 Mt, <4 Euro/tCO_2, uncertainties in E / ER)
  - SF_6 (1 Mt, 3 Euro/tCO_2, uncertainties in E / ER)

Emission reduction options
CH4 - coal mining (1)

Emission breakdown



EU (1990): 62 Mt CO_2

EU (1997): 39 Mt CO_2

CH4 - coal mining (2)

- Recovery and flaring
- Recovery and utilisation
  - as fuel or chemical feedstock in other processes
  - for power generation (on-site)
  - in natural gas pipelines
- Current Utilisation Germany > 30%
  United Kingdom >20%

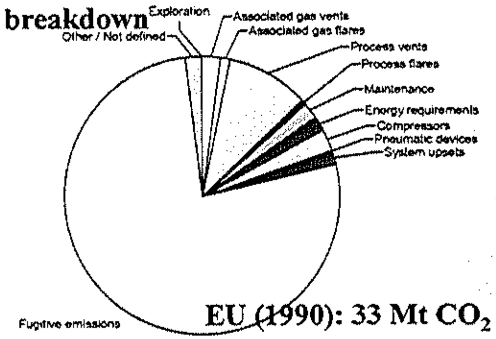
CH4 - coal mining (3)

Reduction options in analysis

- Degasification and power production (6 variants, proven technology)
- Oxidation of ventilation air (in demonstration)
- Reduction potential: 9 Mt CO2-eq. (4 - 20%)
- Costs: between -2 and 2 Euro/tCO_2-eq.

Emission reduction options
CH4 - oil and natural gas (1)

Emission breakdown

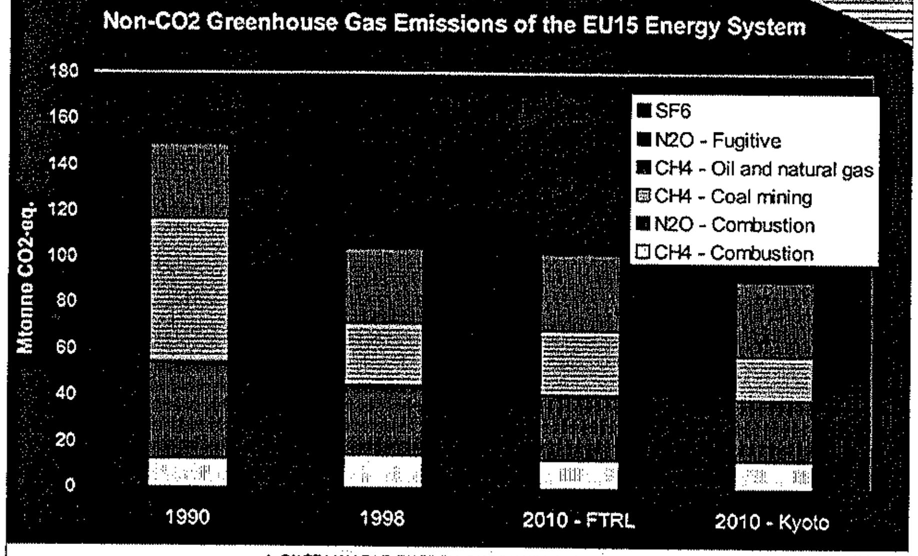


EU (1990): 33 Mt CO_2

EU (1997): 34 Mt CO_2

Emission scenarios

- 1990 and 1998 national inventories
- 2010 frozen technology reference level
  - based on physical indicators of PRIMES baseline
  - including changes 1990-1998
  - 2010 energy sector: 105 Mt CO_2-eq. (8%) (NCGG combustion+fugitives)


Non-CO2 Greenhouse Gas Emissions of the EU15 Energy System

Emission reduction options N2O - combustion (1)

- Use of afterburner (experimental for large scale)

  ER: 90%; Costs: 2-4 Euro/tCO_2;+10% energy input
- Apply reversed air staging ("O_2 management")

  ER: 75%; Costs: 4 Euro/tCO_2; no side effects, test plant
- Optimising operating conditions (T>900 °C)

  ER: 30%-60%; doubling of NOx (SCR)
- Catalytic reduction of N_2O (ER 80%, in dev.)
- Pressurised FBC (ER 80%, test plant)

N2O - combustion (2)

Emissions developments

- Decrease in coal-fired power production
- Little new capacity of FBC
- Emission reduction potential: 2 Mt CO_2-eq.
  - Use of afterburner
  - Apply reversed air staging
- Costs: 2-4 Euro/tCO_2-eq.

Energy related Non-CO2 Greenhouse Gas Emissions

David de Jager, Chris Hendriks (ECO**FYS**)
Judith Bates (AEA Technology)

Outline

- Emission sources
- Emissions 1990, 1998, 2010 baseline
- Emission reduction options
  - N2O combustion
  - CH4 coal mining
  - CH4 oil and natural gas
- Results

Emission sources - Combustion

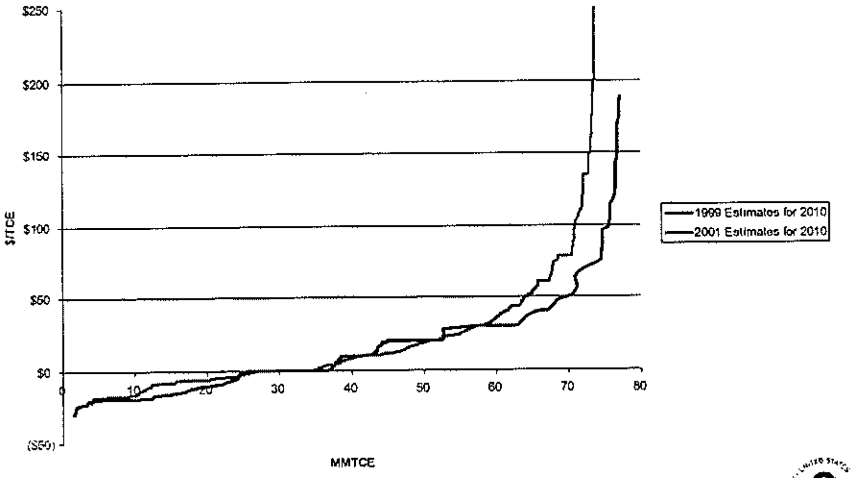
- CH_4: incomplete combustion (0 options)
- N_2O: fuel-NO mechanism (530-730 °C) (coal fluidised bed combustion) (3 options)
  - 10-70 g N_2O/GJ (coal FBC) compared to 1.4 g N_2O/GJ (coal non-FBC)
  - Little information on FBC implementation
  - Share FBC in emission from coal about 55-70%
- N_2O: Selective non catalytic reduction (0 opt.)

Emission sources - Fugitives

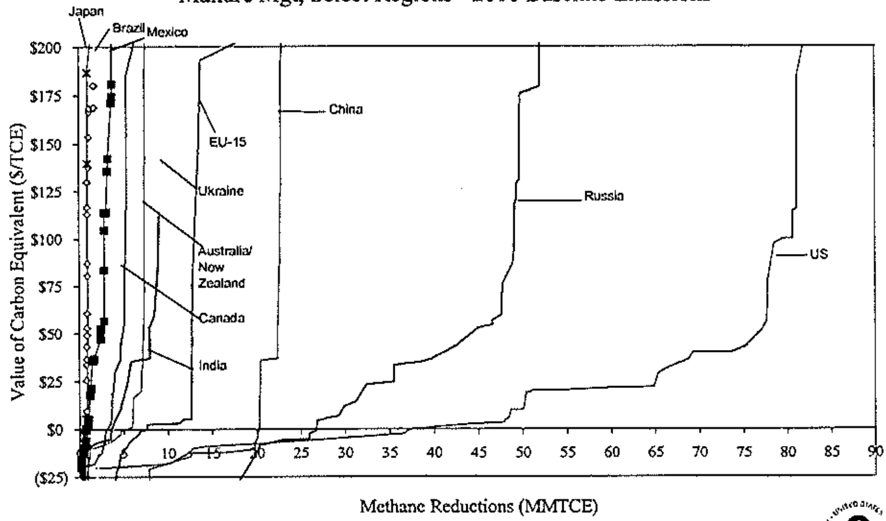
Fossil fuel extraction/transport/distribution

- CH4: fugitive emissions
  - coal mining (4 options)
  - oil and natural gas (20 options)
- (N2O: in fact combustion related emissions)
- SF_6: insulated switch gears (1 option)

Comparison: 1999 Estimates and 2001 Estimates for 2010 Abatement of Methane



Methane Marginal Abatement Curves for Coal, Natural Gas, Landfills, & Manure Mgt, Select Regions - 2010 Baseline Emissions



Methane Uncertainties and Limitations

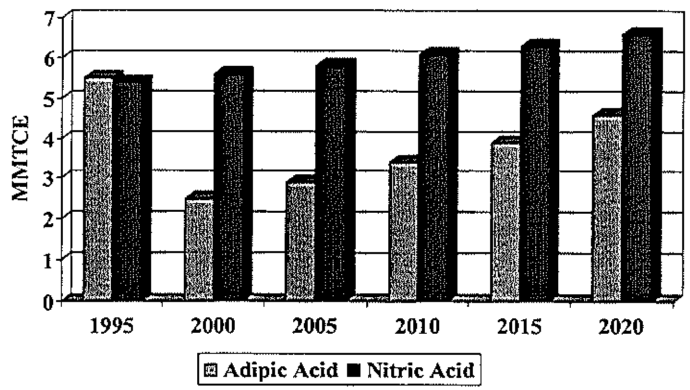
- Size and scale of methane sources over time
- Major focus on currently available technologies
- Lack of data on some of the technologies currently used by industry
- Static - assumes no mitigation up until that year
- Do not currently model enteric fermentation or rice production cost reductions

N_2O Emission Estimates for Adipic and Nitric Acid Production

- U.S. N_2O emissions are based on adipic and nitric acid production

  Example:
  - Adipic N_2O emissions = [production of adipic] x [0.3kg N_2O/kb adipic acid] x [1-(N_2O destruction factor x abatement system utility factor)]

U.S. N_2O Emissions from Adipic and Nitric Acid



Options for Reducing N_2O Emissions from Adipic Acid

Abatement Technology	N2O Destruction Factor	Extent of U.S. Implementation
Catalytic Destruction	90-95%	Two Plants, comprising approximately 63% of U.S. production capacity
Thermal Destruction	98-99+%	One plant, comprising approximately 34% of U.S. production capacity
Recycling/Utilization Technologies	90-98%	In 2000, a 20 thousand metric ton expansion unit at one of the existing U.S. plants will implement an N2O recycling/utilization technology
Recycle to Nitric Acid	98-99+%	None currently.

Options for Reducing N_2O Emissions from Nitric Acid

Abatement Technology	N2O Destruction Factor	Extent of Implementation in the U.S.
Non-Selective Catalytic Reduction	94.7 – 99.1%	Widely installed in plants in the U.S. between 1971-1977
Selective Catalytic Reduction	86%	Approximately 80% of U.S. plants use either SCR or extended absorption.
Extended Absorption	93.5-97%	Approximately 80% of U.S. plants use either SCR or extended absorption.

Cost of Reducing N2O Emissions from Industrial Processes

Abatement Technology	Cost (1996$/TCE)				Emission Reductions (MMTCE/Year)			
	2005	2010	2015	2020	2005	2010	2015	2020
Adipic Acid (Thermal)	0.77	0.78	0.78	0.80	0.56	0.56	0.56	0.56
Nitric Acid (Incremental NSCR)	9.45	9.48	9.51	9.82	0.10	0.10	0.10	0.10
Nitric Acid (Replacement NSCR)	4.46	4.49	4.51	4.83	0.10	0.10	0.10	0.10

Uncertainties and Limitations

- Analysis for industry sources is largely complete; mobile and agricultural sources are not included
  - confidential business information
- Based on 1991 estimates for costs of NO_x controls - it is likely costs are overestimated.
- Estimates do not include recovered heat
- Many nitric acid production facilities are between 20 and 30 years old, making capital turnover cheaper when plants are rebuilt.

Next Steps

- Working with modelers to include methane in "top-down" models and "bottom-up" models
- Technology costs updated; technologies seen on the horizon added
- Expanding the analysis to 2050

For More Information:

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EC Sector Objectives - Fluorinated Gases

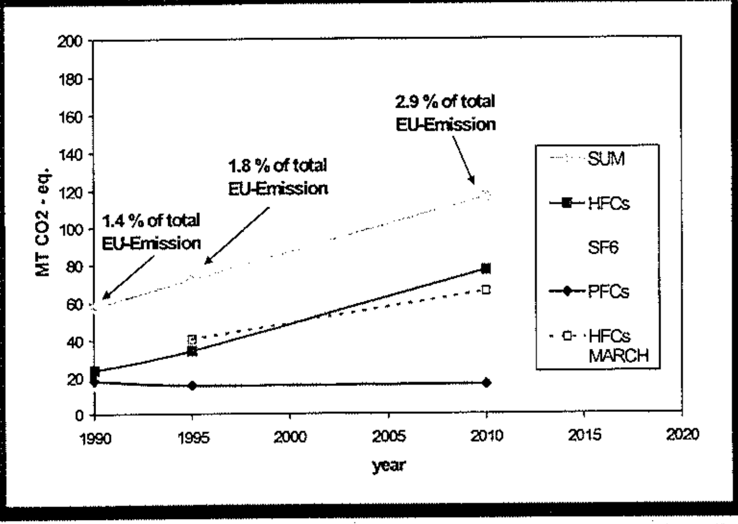
Brussels - June 13, 2001
Non-CO_2-GHG Expert Network

Jochen Harnisch, Ecofys Germany

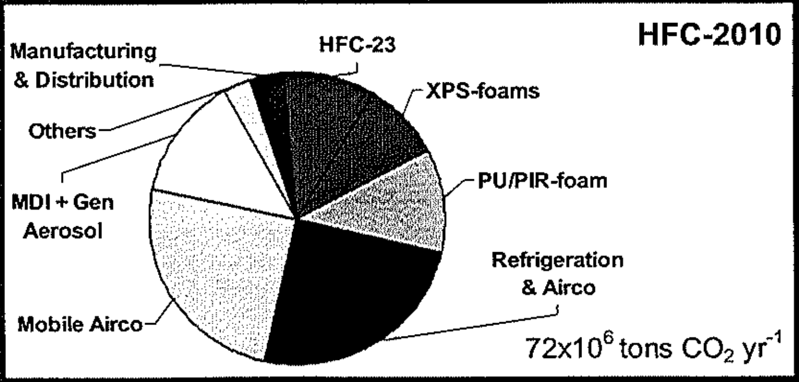
Presentation Outline

- Emission model for EU-15
- Abatement Options for HFCs, PFCs and SF_6
- Abatement cost curve
- Robustness of results
- Conclusions from study
- Experience from European Climate Change Programme
- Recommendations for future work

Projected EU-15 Emissions of HFC, PFC and SF_6

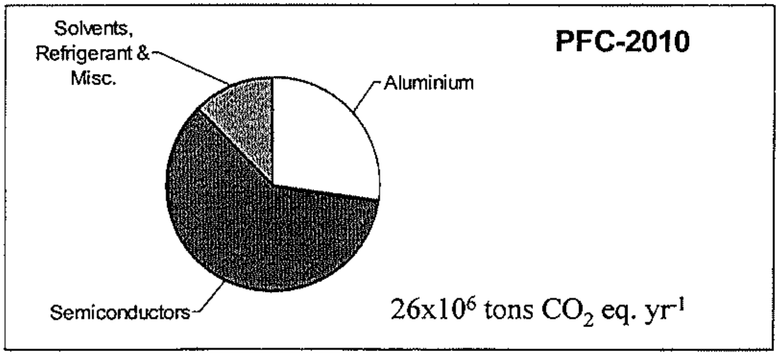


EU-15: HFCs in 2010



ECOFYS

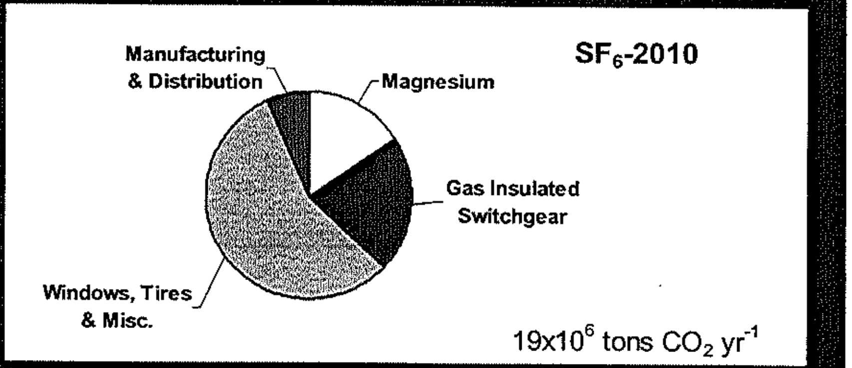
EU-15: PFCs in 2010



$26x10^6$ tons CO_2 eq. yr^{-1}

ECOFYS

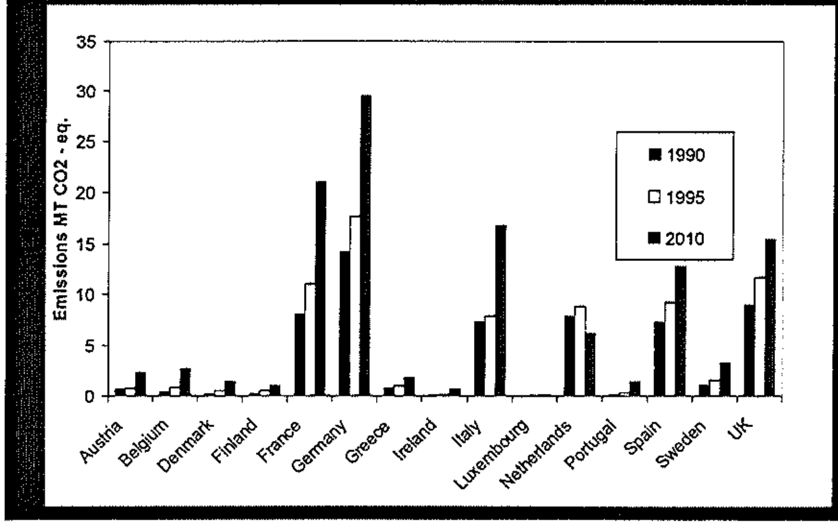
EU-15: SF_6 in 2010



$19x10^6$ tons CO_2 yr^{-1}

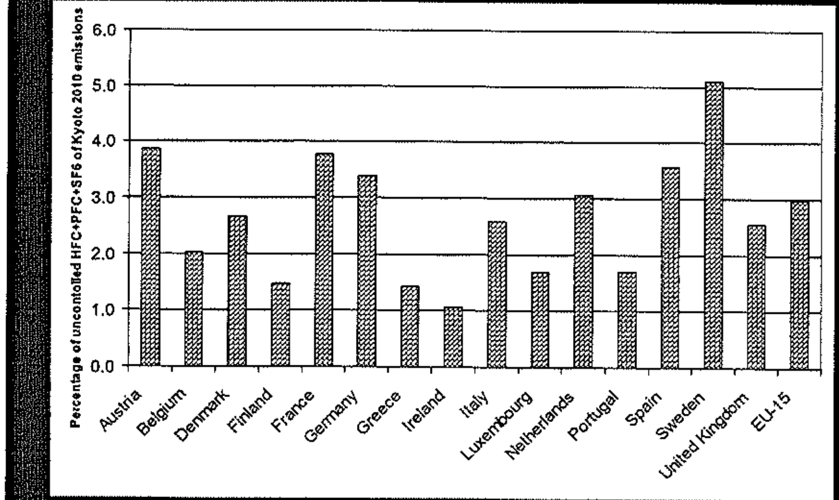
ECOFYS

National Emissions of HFC, PFC & SF_6

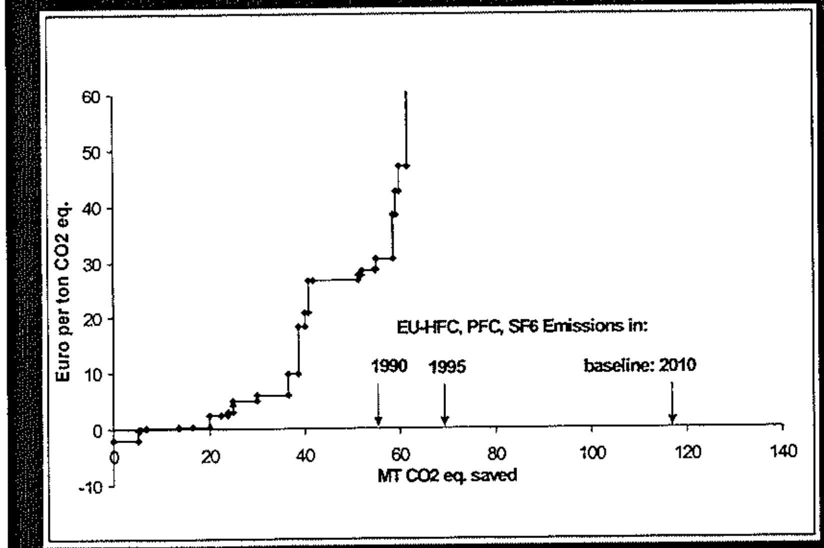


ECOFYS

Relevance of uncontrolled F-Gases in 2010



Combined Abatement Curve EU-15



Robustness of results

Robust	Not very robust
• EU 1990/95 Emissions	• National break-up
• Upper limits of costs	• Reference emission projections for 2010
• Foam sector	• Choice of specific technological solution
• Point sources	• Alternatives in Refrigeration and air-co sector
• Conservative Treatment of "Energy Penalties"	

Conclusions (1)

- Emissions of <u>HFCs</u>, PFCs and SF_6 are projected to grow by +50 to +150% by 2010 relative to 1995
- In 2010 F-gases will contribute 1-5 (3) % of national (EU) GHG emissions compared to 1-3 (2) % in 1995.
- Countries without a control on HFCs, PFCs and SF_6 emissions will need to find additional reduction options for the other greenhouse gases

Conclusions (2)

- Reduction potential of several 10% of projected 2010 baseline emissions of HFCs, PFCs and SF_6 available at below US$ 10 per ton of CO_2 equivalent
- Significant inter-regional differences exist regarding the baseline implementation of reduction measures
- Energy efficiency and safety issues are perceived differently across Europe

Experience from ECCP

- It is possible (though difficult) to achieve a temporary consensus on numbers
- Technical reduction potentials and specific abatement cost data were mainly used during the scoping phase of ECCP
- History of conflict and public pressure in the end determine technology choices
- Policies generally have winners and losers
- Specific abatement costs do not reflect share of cost in value added in a given application

Priorities on EU Level

- Combine work on emission models with national and EU inventory and reporting efforts
- Complete evaluation of abatement options for all sources (e.g. technical aerosols, solvents)
- Improve knowledge on emissions and abatement options in key applications (e.g. mob. air conditioning, refrigeration, switchgear)
- Update data base on reduction options and carry out prospective work on new technologies
- Provide assistance for similar work in the accession countries

U.S. High GWP Gas Emissions Inventories, Projections and Opportunities for Reductions
1990-2010

Sally Rand
Office of Atmospheric Programs
U.S. EPA

EPA

June 14, 2001

The Importance of High GWP Analysis for Climate Protection

- Inform Policy Makers
  - Big Picture, Priorities, Strategies
- Focus and Inspire Companies
  - Responsibility and Opportunity
- Empower Consumers, Voters, Activists
- Train Next-Generation Climate Team

Analytical Goals

- Policy-Relevant Information in National and Global Context
- Transparent Assumptions and Techniques
- Credible Attention to Uncertainty
- Honest and Clear Presentation

U.S. Sources of High GWP Gases

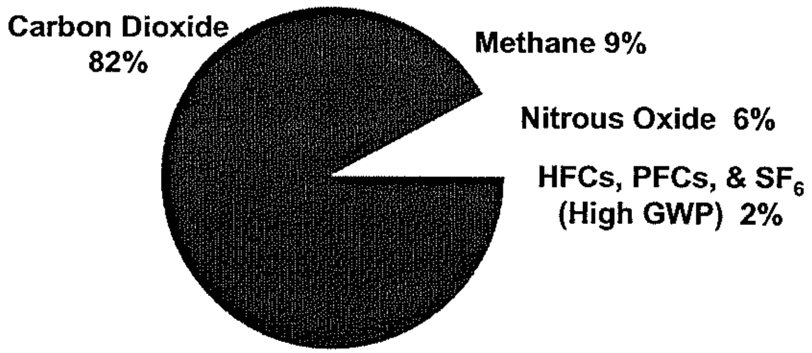
- From the ODS substitutes – Refrigeration & A-C, Foams, Solvents, Fire Extinguishing, Aerosols
- SF_6 from Electric Utilities, Magnesium Smelting
- PFCs from Aluminum Smelting and Semiconductor Manufacture
- HFC-23 from HCFC-22 production

1995 U.S. Climate Change Action Plan (CCAP)

- Voluntary programs
  - All major PFC & SF_6, HFC-23 sources
  - Aluminum, Electric Power Systems, HCFC-22 Manufacture, Magnesium, Semiconductors
  - 13 MMTCE by 2000, 17.4 MMTCE by 2010
- Regulatory (in baseline)
  - ODS Substitutes, Recovery/Recycling
- New initiatives expected in ODS sectors

1999 U.S. Greenhouse Gas Emissions

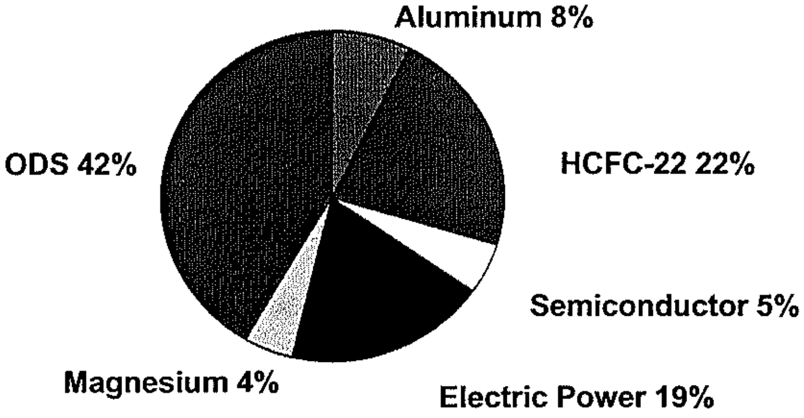
(GWP-weighted)



Total 1999 U.S. GHG Emissions = 1,838.3 MMTCE

Source: *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1999.* EPA, 2001.

1999 High GWP Sector Emissions



Total Emissions = 37 MMTCE

Source: *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1999.* EPA, April 2001

Emissions Estimate Methodology

- By sector
- Establish base year
- Estimate annual emissions
- Forecast future emissions

Emissions Estimate Methodology

- Variety of resources for each gas and source
  - published studies
  - industry communication & reporting
  - EPA Vintaging Model
- In some cases, activity factors and emission factors were applied to production data
- Consistent with IPCC Good Practice Methods

EPA Cost Analysis Methodology

- Identify emission reduction technologies and practices
- Estimate achievable savings (GHG reductions) from each technology/practice
- Investigate costs of each technology/practices (capital, O&M costs) and economic life
- Solve for carbon-equivalent price for the savings that yield NPV of $0 (4 & 8% discount)

Assumptions

- BAU assumes no further actions beyond 2000
  - Although significant voluntary reduction expected
- Anticipate technology
  - Not all options are technically proven or commercially available
- Use for Macro-modeling not micromanage
  - Does not evaluate technical challenges, comparative advantages

High GWP Gases MAC

- Main issues raised
  - indirect CO_2 emissions from energy-efficiency effects of options
  - rapid evolution of technology
- Accounting for indirect emissions
  - If an alternative uses more energy, CO_2 emissions could increase
  - Results vary by use, appliance, source of energy (e.g., hydro vs. coal)

Life Cycle Climate Performance (LCCP)

- Net impact of use or replacement of gas
  - change in energy consumption
  - change in CO_2 from power generation
- Consider manufacture of chemical and disposal of equipment
- Refrigeration, Air Conditioning, Foams

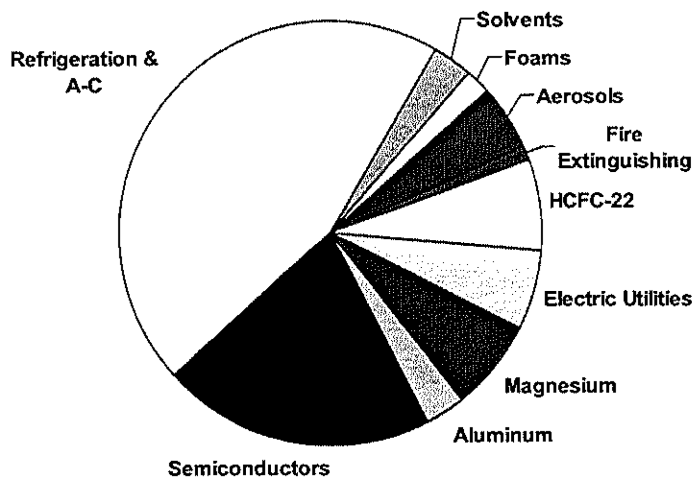
Historic and Current Emissions
1990-1999

- Based on source-specific emission and activity factors
- Use annual industry/source activity data
- Update emission factors for technology change and equipment turnover

Emissions Forecasts
2000-2010

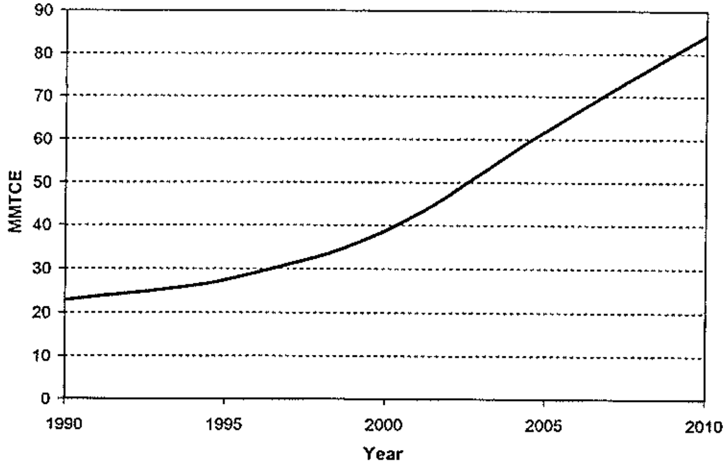
- Future baseline "business as usual" emissions starting point for cost analysis
- Baseline does not include expected "CCAP" voluntary reductions
- Baselines use most recent emission inventory and projections of emissions and activity factors

Projected (2010) U.S. High GWP Gas Emissions



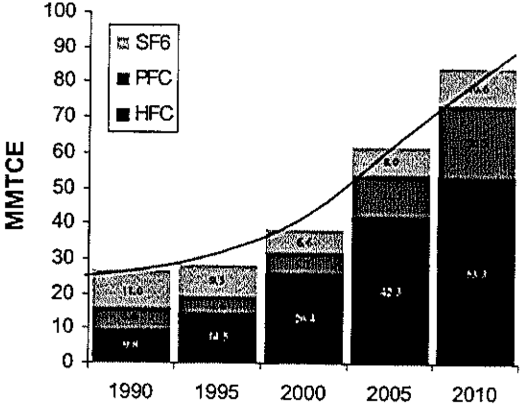
Total 2010 High GWP Gas Emissions = 84.2 MMTCE

U.S. Total High GWP Gas Emission Estimates & Projections



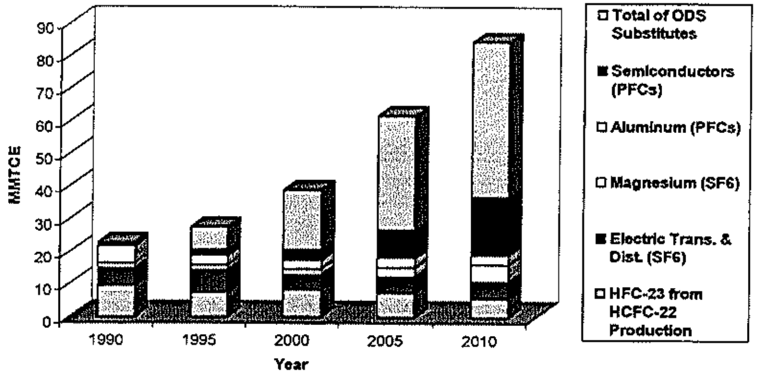
U.S. High GWP Gas Emission Estimates & Projections by Gas

Baseline Projections do not include U.S. Climate Change Action Plan reductions



U.S. High GWP Gas Emission Estimates & Projections by Sector

Baseline Projections do not include U.S. Climate Change Action Plan reductions

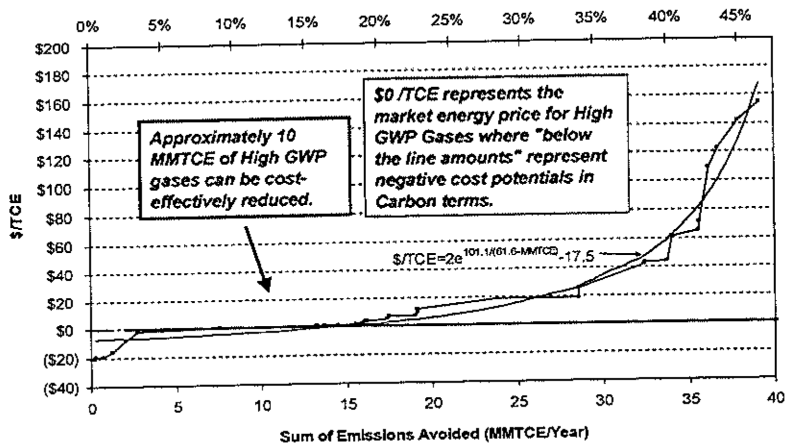


Marginal Abatement Curve (MAC)

- Rank order of individual opportunities by cost per emissions reduction
- $0/TCE set to market price of abated GHG
- Any point along a MAC represents the marginal cost of avoiding an additional ton of carbon-equivalent emissions

U.S. High GWP Marginal Abatement Curve for 2010

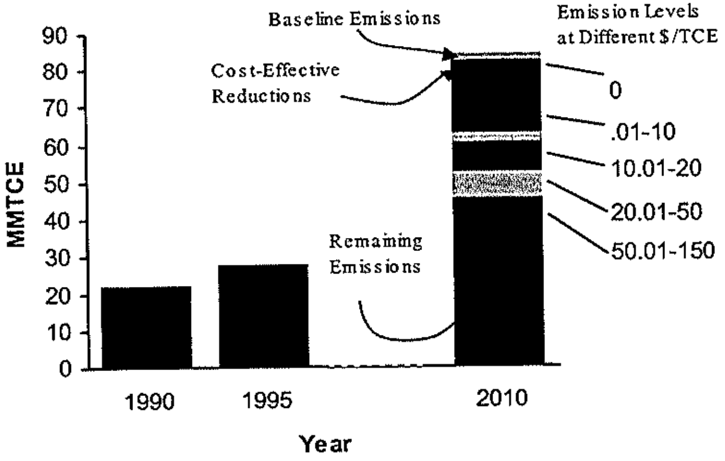
(at an 8 percent discount rate)



Approximately 10 MMTCE of High GWP gases can be cost-effectively reduced.

$0 /TCE represents the market energy price for High GWP Gases where "below the line amounts" represent negative cost potentials in Carbon terms.

Projected U.S. Emission Reductions - High GWP Gases



Report Conclusions

- 10 MMTCE achievable through reduction opportunities at low cost
- Estimated emission reductions at a carbon value of $20 per TCE are 32 MMTCE
- Estimated emission reductions at a carbon value of $100 per TCE are 39 MMTCE

Uncertainties / Limitations

- Reduction options and relevant costs
  - Data proprietary in many cases
  - Reduction estimates preliminary
- Not all options technically proven or commercially available
- Efficiency and other technical improvements expected in the future
- Future energy prices uncertain
- Transition from ODS to HFCs and other alternatives on-going

Next Steps

- Add new technologies
- Update technology costs
- Improve emission models
- Increase industry participation
- International MACs

International High GWP Marginal Abatement Curve

- Extend forecast through year 2020
- Regions including –
  - U.S.
  - E.U.
  - Developing Countries
  - Other Annex B

Optimistic Time Frames

- Technology Reinvention 1 to 10 years
- Economic Forecasts 5-10 years
- Market Transformation 5-25 years
  - Telecommuting, Urban Revitalization, Trains Faster Than Planes, Natural Architecture, Total Recycle, Zero-Waste, …
- 100 Year Technology Forecasts?

Useful Approach?

- *Available Technology* Abates Current Emissions (0-5+ years) @ Estimated Cost
- *Pollution-Prevention Technology* Lowers Emissions (2-10+ years) @ Costs Less-than Abatement; Lower Achievable Emissions
- *Design-for-Environment Technology* Further Reduces Emissions and Costs (10- 20+ years)
- *Social and Market Transformation* Low Emissions from Sustainable Economy

Network Collaboration

- Foster data sources, especially in industry
- Ensure comparability
- Anticipate technology change
- Expand peer review
- Share plans and pool resources???

For More Information

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"U.S. High GWP Gas Emissions 1990-2010: Inventories Projection and Opportunities for Reductions"
http://www.epa.gov/globalwarming/publications/emissions/index.html

What are the Gains from a Multi-Gas Strategy?

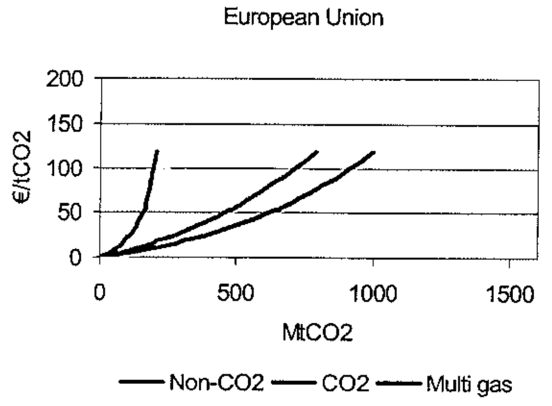
Jesper Jensen

Copenhagen Economics

Multi-gas climate policies

- The Kyoto Protocol:
  - 5% cut in aggregate Annex B emissions
  - Target applies to a basket of six gases
- Gains from a multi-gas strategy?
  - Two scenarios: MultiGas and SingleGas
  - Cost-effective abatement
  - Unlimited Annex B trade with all emissions

Key results



What is new?

- Existing multi-gas analyses:
  - Reilly *et al.* [1999]
  - Burniaux [2000]
  - Manne & Richels [2000]
- Our contributions:
  - Apply identical targets
  - Estimate marginal abatement costs curves
  - Sensitivity analysis

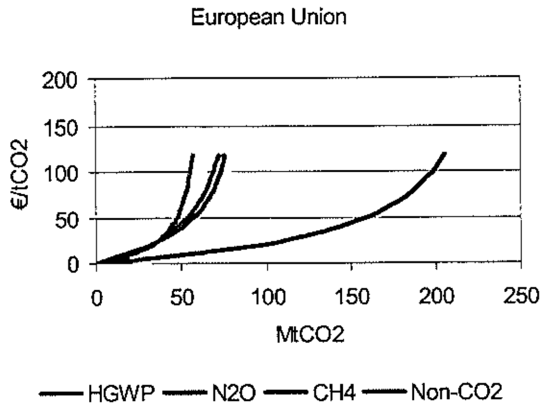
Non-CO_2 emissions

Base year data: UNFCCC inventory data
Baseline emissions: National communications

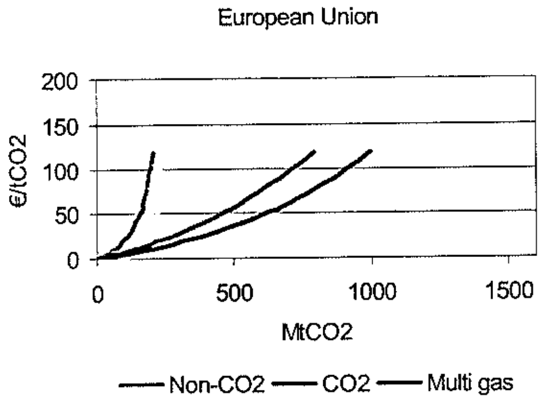
Bottom-up analyses:
- Estimate abatement costs by technology
- Effectively points on MACs

We estimate economy-wide MACs
- CH_4, N_2O and HGWP for the EU and the US
- 100-year GWP to convert to tCE

MACs for non-CO_2 emissions



Aggregate MACs



The EDGE model

Dynamic general equilibrium model
- Global model with 8 regions

7 production sectors
- 5 energy sectors
- Y=f(K,L,E,M)

Ramsey-type representative agent
- $W=f(C_{2000}, C_{2005}, \ldots, C_{2030})$

Scenarios

Common assumptions:

- Compliance with Kyoto targets
- No revenue recycling
- Unlimited Annex B emissions trading

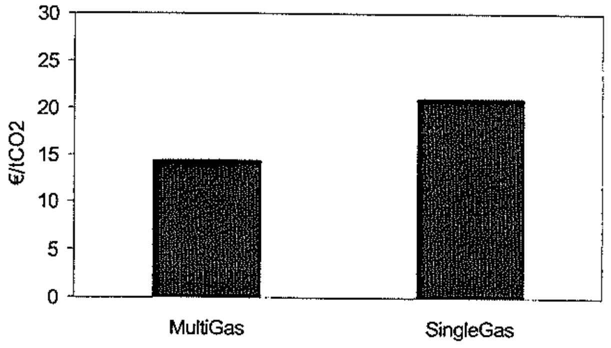
SingleGas: Control of CO_2 only

- Least-cost strategy across CO_2 emissions

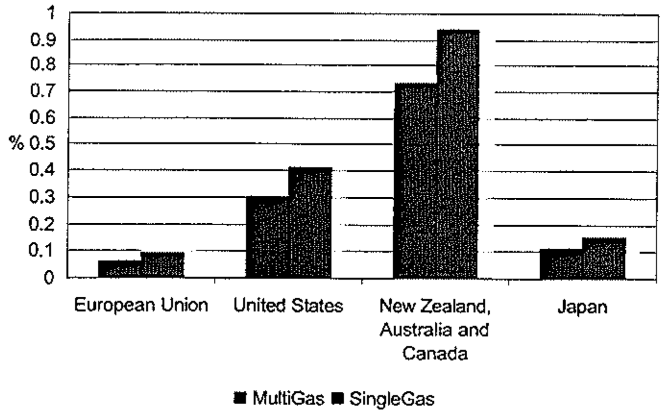
MultiGas: Control of all emissions

- Least-cost strategy across all emissions

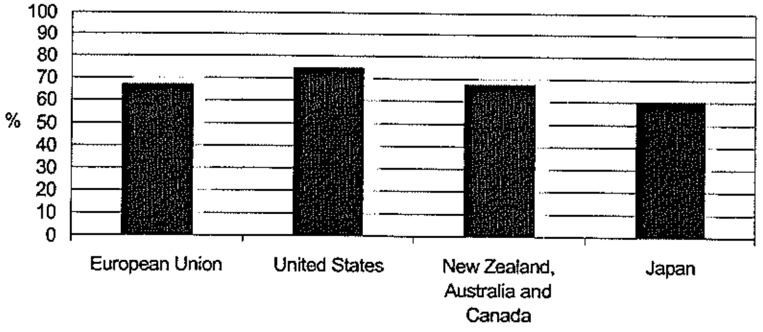
Marginal abatement costs



Welfare costs



Share of CO_2 abatement



Concluding remarks

A multi-gas strategy implies:
  Lower costs
  More domestic action

Extensions of the analysis
  MACs for other countries
  Better estimates of baseline emissions
  Costs of sinks projects

Multiple Gas Control Under the Kyoto Agreement

Jochen Harnisch, Francisco de la Chesnaye and John Reilly

MIT Joint Program on the Science and Policy of Global Change

Reference Projections of Trace Gases and EPPA Activities*

Trace Gas	Anthropogenic Emission Sources	EPPA Activities
CH_4	Rice production, livestock waste, enteric fermentation, land fill waste, natural gas venting and distribution losses, coal seam gas, biomass burning	Agricultural production, natural gas production, coal production, exogenous biomass burning from deforestation
N_2O	Fertilized soils, Adipic and nitric acid production, catalytic converters in vehicles, biomass burning	Agriculture production, other industry production, refined oil production, exogenous biomass burning from deforestation
PFCs	Aluminum & semiconductors production, solvent use, other	GDP
HFCs	Refrigeration & air conditioning, solvent & foaming agent use, by-product of HCFC production	GDP
SF_6	High voltage switch gears, magnesium production & semiconductor production, other	Electricity use, GDP

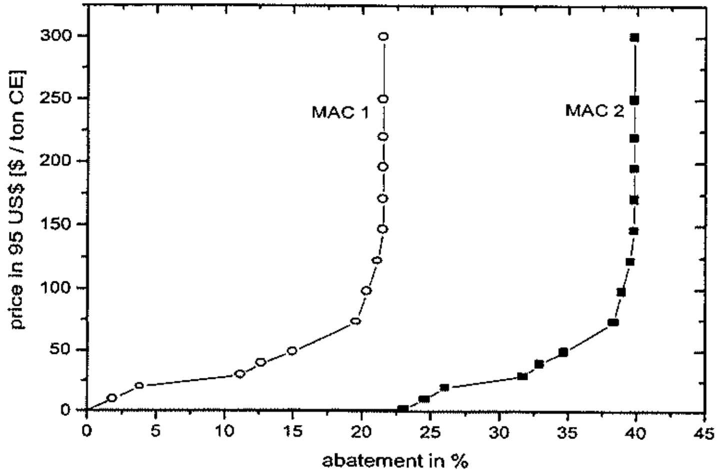
*SO_x, NO_x, and CO are also projected for purposes of linking with an atmosphere/climate model.

The four cases

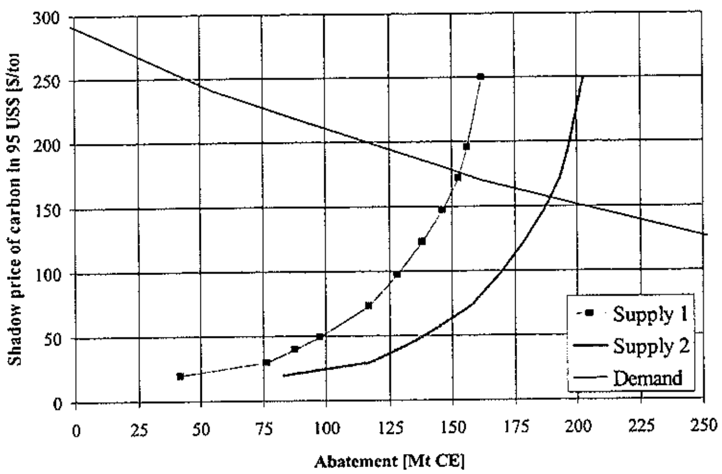
1) CO_2-Target + CO_2 control
2) Multi-Gas Target + CO_2 control
3) Multi-Gas Target + Multi Gas Control (MAC2)
4) Multi-Gas Target + Multi Gas Control (MAC1)

From: J. Reilly, M. Mayer, J. Harnisch; Multiple Gas Control under the Kyoto Agreement; MIT-Joint Program, March 2000.

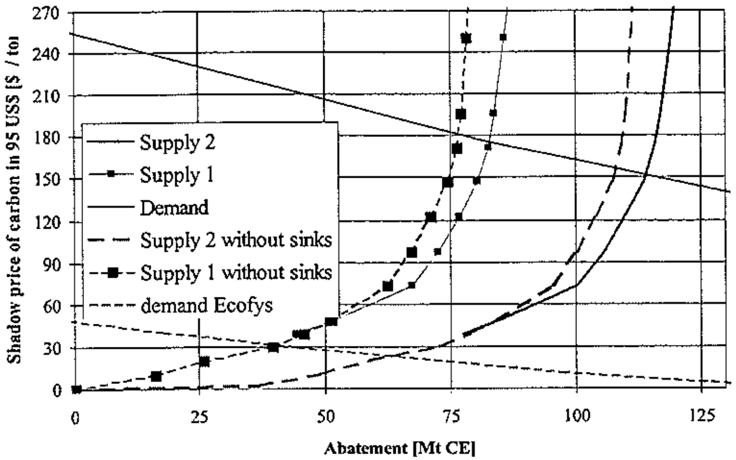
Marginal Abatement Curves for Methane in 2010



USA



EEC



2010 Reference Emissions, Percentage Growth from 1990

GAS	USA	JPN	EEC	OOE	EET	FSU	EEC 1
CO_2	37.7	28.2	27.9	37.8	-9.6	-10.1	8
CH_4	8.2	21.1	10.9	21.3	27.3	34.8	-27.1
N_20	31.1	47.3	28.7	36.3	19.1	25.7	7.9
SF_6	21	40	23.4	27.3	60	9.4	-13.2
HFC	124.4	152.2	132.9	144	240	187.5	75.2
PFC	-32.4	-76.9	-31.7	-29.2	-18.2	-14.5	-26.3
Total	**34.7**	**29.8**	**26.5**	**34.2**	**-1.3**	**-3**	**4.5**
Required reductions, percentage reduction from 2010 reference							
CO_2-only, Case 1	32.5	26.7	28	31.4	-2.9	-9	12.7
Multi-gas, Cases 2-4	31	27.6	27.3	29.6	5.8	-1	11.7

EEC 1 is an alternative scenario for the EEC based on de Jager et al. 1999 projections.

Shadow Prices and Total Cost of Abatement

	USA	JPN	EEC	OOE	EET	EEC 1
	Shadow Price (US$/ton CE)					
Case1	258	305	210	271		49
Case 2	360	386	281	465	22	56
Case 3	156	250	151	100	11	23
Case 4	176	260	175	131	2	31
	Total Costs (US$ x 10^9)					
Case 1	61	14	29	12	0	3
Case 2	86	19	45	24	0.2	4
Case 3	38	12	22	5	0.02	1
Case 4	43	13	27	7	0.1	2

EEC 1 is the alternative scenario for the EEC based on de Jager et al. 1999 projections.

Abatement by GHG, Percentage of Total Abatement, Case 3

Gas	USA	JPN	EEC	OOE	EET	EEC I
CH_4	9.8	3.2	13.5	21	79.8	26.8
free CH_4	3	0.4	2.6	5.1	2.1	2
N_2O	6.3	3.2	6.3	5.3	1.5	10.4
free N_2O	1.8	1.8	1.4	0.8	0.1	1.1
SF_6	1.3	3	1.4	1.8	0.5	2.3
HFC	3.6	8.2	4	2.1	0.1	2.7
PFC	0.5	0.2	0.5	2.1	0	0.5
Total Other GHGs	26.2	18.8	27.1	48.4	81.9	42.7
Sinks	4.6	1	1.5	16.1	0	0
Carbon	69.1	79	68.9	45.7	16	54.2

Challenges

- Representation of Non-CO_2 GHGs should be consistent with General Equilibrium Concept
- Appropriate links with economic sectors
- Identification of economic driving factors vs. independent technological evolution
- Representation of Non-CO_2 GHGs should be kept simple and flexible

Outlook: Non-CO_2 GHGs in MIT-EPPA

- Improve modelling of Non-CO_2 reference emissions
- Endogenisation of Non-CO_2 abatement costs into production functions
- Incorporate new cost curves specific for regions and sectors

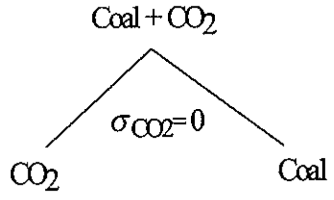
EPPA With Endogenous Methane Abatement

- Results from Rob Hyman's Master's Thesis, with John Reilly as supervisor
- Methane emissions and activities in EPPA
- Method for including
- Some policy simulations

EPPA: Other Versions

- Full Dynamic Version ~30 hours solution time
- Developing Country Disaggregation (19 developing + 6 developed countries/regions)
- EU-Transportation Disaggregation (10 EU + 5 developed+ 6 developing countries/regions with commerical and household transportation sectors)
- OECD With Distortionary Labor, Capital, Consumption, and Energy Taxes
- Endogenous GHG Costs

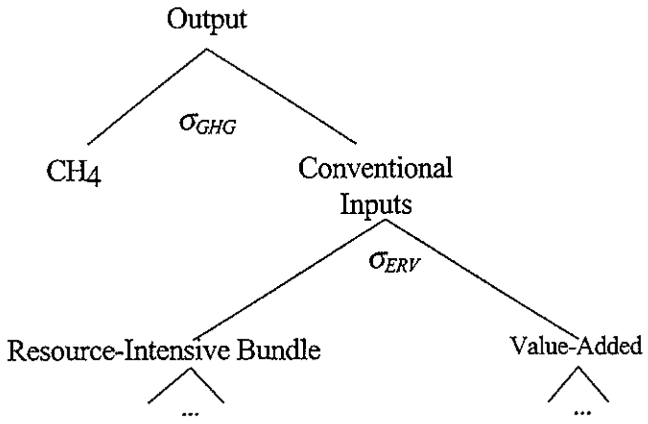
CES Nest Structure for CO_2: Coal



Methane Sources and EPPA Sectors

Coal Mining	Coal Production
Gas Flaring	Oil Production
Natural Gas Distribution	Gas Consumption
Livestock, Rice, Biomass	Agriculture Production
Landfills/waste water	Household consumption
Industrial sewage (paper and chemicals)	Energy intensive industry
Industrial sewage(food processing)	Other industry

CES Nest Structure for CH_4:Agriculture

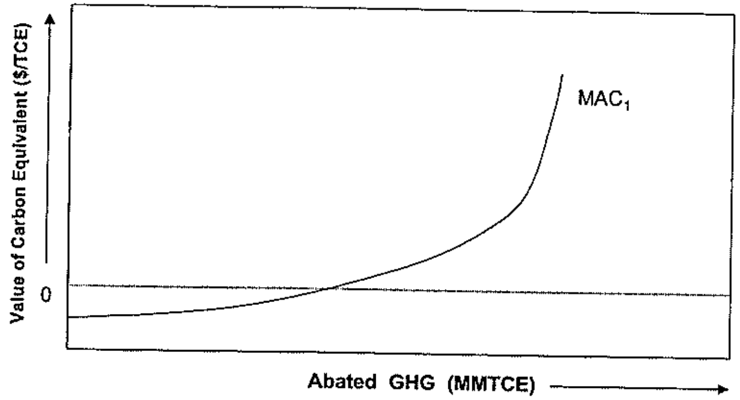


Method

- Use detailed cost information to construct supply curves (MACs) from US Environmental Protection Agency, IEA
- Fit σ MAC
- Create CES nests in EPPA for CH_4

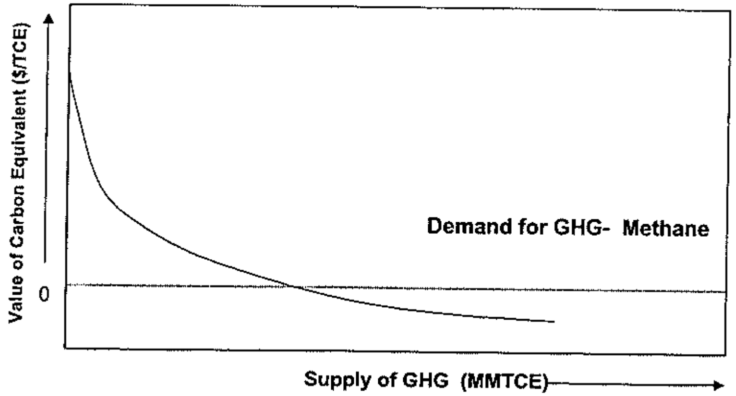
From MACs-Supply to Input Demand Function

Illustrative non-CO2MAC



From MACs-Supply to Input Demand Function

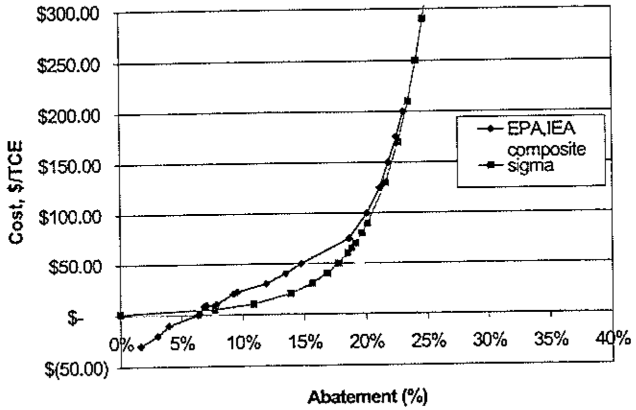
Illustrative non-CO2MAC



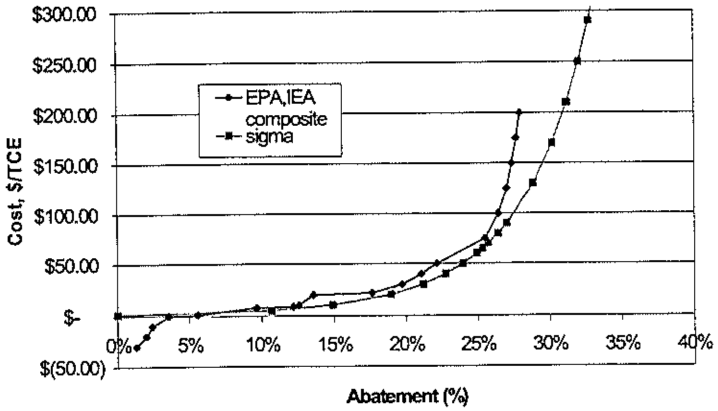
Data Sources

EPPA Sector	Emissions Source	MAC Data Sources
AGRIC	Enteric fermentation	Assumed no abatement
	Manure decomposition	US EPA
	Rice cultivation	IEA
GAS	Gas production and distribution	US EPA
OIL	Oil production	Assumed same MAC as GAS
COAL	Coal production	US EPA
ENERINT	Industrial sewage	IEA
OTHERIND	Industrial sewage	IEA
Final Demand	Landfill	US EPA
	Domestic sewage	IEA

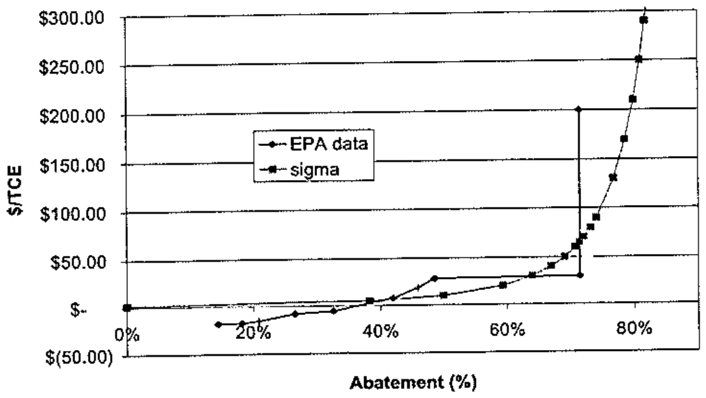
Agriculture: USA



Agriculture: China



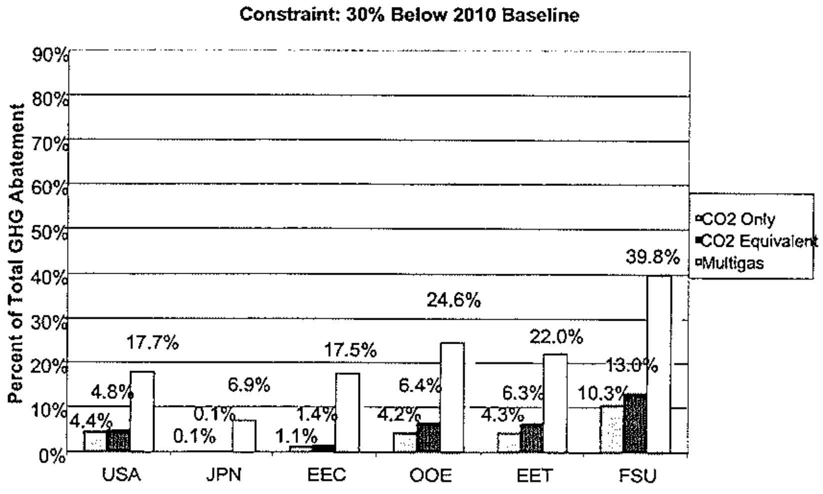
Coal Production: USA



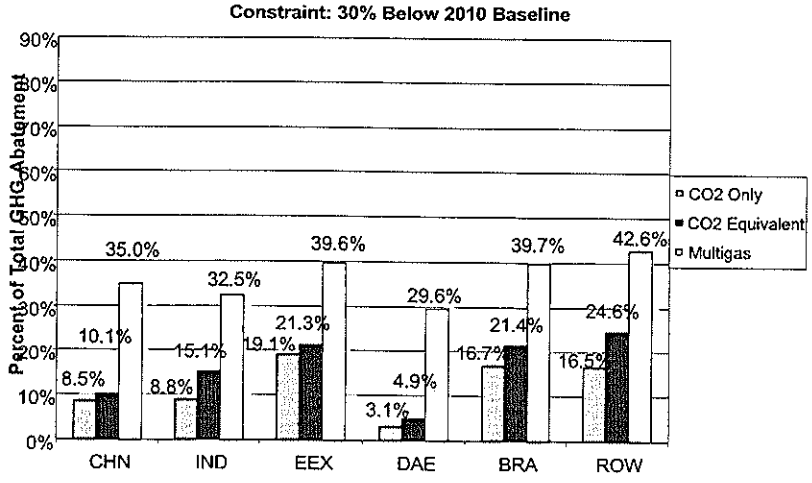
Policy Results

- Consider 10 and 30 percent reductions **from 2010 Reference**
- 3 Cases
  - Reduction based on CO2 reference only
  - Reduction based on CO2+CH4 reference but no restrictions on CH4
  - Reduction based on CO2+CH4 reference with restrictions on CH4

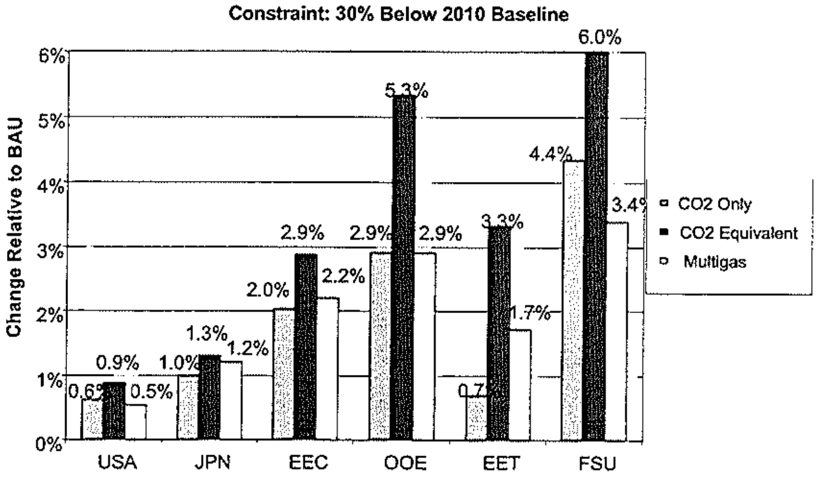
Methane Abatement-Developed Countries



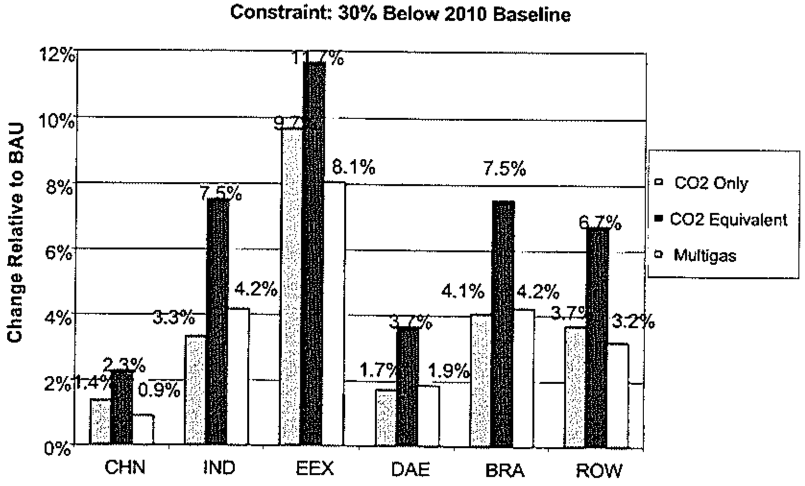
Methane Abatement-Developing Countries



2010 Welfare Impacts-Developed Countries



2010 Welfare Impacts-Developing Countries



Conclusions

- Costs among countries are far different with equal percentage reductions and methane included than under Kyoto targets and CO2-only
- Equal percentage reductions for CO2 compared with Kyoto targets
  - Kyoto differences dominated by reference growth
  - Our cases show effects of economic structure
- Reasons for Differences
  - Energy exporters (e.g.FSU/EEX) and importers (e.g. US)
  - Reliance on coal (US, China, India)
  - Current energy taxation (Europe)
  - Efficiency of the economy (Japan)

Conclusions (cont.)

- Methane is very important, more so in developing countries.
  - In a CO2 and methane abatement strategy with small reductions from reference (10%), methane contributes 40 to 55% of abatement in most developed countries and 65 to 80% in developing countries
  - Methane abatement opportunities are limited, at least based on assessment of current technology, so that with larger reductions (30%) methane contributes 17 to 25% of the reduction in developed countries and 32 to 43% in developing countries.

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Acknowledgements

This work made use of the SEM and TEM facilities of the Center for Advanced Microscopy at Michigan State University. Financial support from the National Science Foundation is gratefully acknowledged.

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An alternative approach to establishing trade-offs among greenhouse gases

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The Kyoto Protocol permits countries to meet part of their emission reduction obligations by cutting back on gases other than CO_2 (ref. 1). This approach requires a definition of trade-offs among the radiatively active gases. The Intergovernmental Panel on Climate Change has suggested global warming potentials for this purpose[2], which use the accumulated radiative forcing of each gas by a set time horizon to establish emission equivalence. But it has been suggested that this approach has serious shortcomings: damages or abatement costs are not considered[3–10] and the choice of time horizon for calculating cumulative radiative force is critical, but arbitrary[5]. Here we describe an alternative framework for determining emission equivalence between radiatively active gases that addresses these weaknesses. We focus on limiting temperature change and rate of temperature change, but our framework is also applicable to other objectives. For a proposed ceiling, we calculate how much one should be willing to pay for emitting an additional unit of each gas. The relative prices then determine the trade-off between gases at each point in time, taking into account economical as well as physical considerations. Our analysis shows that the relative prices are sensitive to the lifetime of the gases, the choice of target and the proximity of the target, making short-lived gases more expensive to emit as we approach the prescribed ceiling.

Although the Kyoto Protocol encompasses a number of radiatively active gases, the assessment of compliance costs has focused almost exclusively on the costs of reducing carbon dioxide (CO_2) emissions. This is because CO_2 is, by far, the most important man-made gas[2]. Also, until recently, few economic models have been able to conduct comprehensive multi-gas analyses[10]. Moreover, the quality of data pertaining to other greenhouse gases is poor (both spatially and intertemporally). Nevertheless, focusing exclusively on CO_2 will bias mitigation cost estimates and lead to policies that are unnecessarily costly.

A number of gases have now been identified as having a positive effect on radiative forcing. We consider the three that are thought to be the most important: CO_2, methane (CH_4) and nitrous oxide (N_2O) (ref. 2).We also consider the cooling effect of sulphate aerosols, but exclude the 'second basket' of greenhouse gases included in the Kyoto Protocol. These are the hydrofluorocarbons (HFCs), the perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). We believe that these omissions do not alter the key insights of our analysis.

Table 1 shows alternative global warming potentials (GWPs) for the three gases of interest. The index is defined as the cumulative radiative forcing between the present and some time in the future caused by a unit mass of gas emitted now, expressed relative to that of CO_2 (ref. 2). Clearly, the choice of time horizon is critical. Unfortunately, as pointed out in ref. 5, there is no justification for choosing one time horizon over another. GWPs are a purely physical measure. They depend neither on damages nor mitigation costs. For a discussion of the uncertainties involved in calculating GWPs, see ref. 11.

What might then constitute a more defensible index for establishing trade-offs among gases? Ideally, the index would be the outcome of an analysis that minimizes the discounted present value of damages and mitigation costs. Unfortunately, we lack at present the necessary knowledge to specify the shapes of the damage functions and to assign values to many categories of impacts. We have therefore used an approach in which the ceiling is intended to reflect a political judgement as to what constitutes a prudent limit. These limits are based upon expectations regarding the damages associated with particular ceilings. The appropriate trade-offs among gases are then determined through a cost-effectiveness analysis.

Unlike the calculation of GWPs, the proposed approach incorporates the marginal cost of abating each greenhouse gas. This can have important implications for the trade-offs among gases. The more expensive it is to abate a particular gas, the smaller the role of that gas in a multi-gas reduction portfolio. Relying completely on

Table 1 GWPs as a function of alternative time horizons

Species	Chemical formula	Lifetime (years)	Global warming potential (years)		
			20	100	500
Carbon dioxide	CO_2	50–200	1	1	1
Methane	CH_4	12	56	21	6.5
Nitrous oxide	N_2O	120	280	310	170

Data from ref. 2.

purely physical measures to determine the trade-offs among gases ignores this potentially important consideration.

The proposed approach is consistent with the UN Framework Convention on Climate Change[12], which has as its ultimate goal the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system". As there are many ways of achieving this goal, the Framework Convention goes on to state that "policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost" (ref. 12).

The analysis is based on a computable general equilibrium (CGE) model called MERGE. (For a description of the model and its key inputs, see http://www.stanford.edu/group/MERGE). The version used in the present analysis integrates submodels that provide a reduced-form description of the energy sector, the economy, emissions, concentrations and temperature change. MERGE is disaggregated across both space and time. The globe is divided into nine geopolitical regions. The choice of time horizon is contingent upon the issue under study. For the current application, it is necessary that the proposed ceiling be binding within the time horizon of the model. Here, 200 years are sufficient.

It is particularly important for the present analysis to be able to calculate the prices of the various greenhouse gases. That is, for a given ceiling, these prices express how much one should be willing to pay to emit an additional ton of each gas. The trade-offs among gases are then based on the relative prices of each gas as determined by its contribution to the ceiling.

Here we focus on temperature change (both absolute and decadal). However, we stress that the approach is applicable to any ceiling to which the greenhouse gases contribute. In addition to identifying an economically efficient temperature profile for satisfying a particular temperature goal, MERGE also identifies the corresponding concentration profiles and emissions trajectories.

We begin by assuming that the goal of climate policy is to limit the future increase in mean global temperature. Using MERGE, we identify an economically efficient strategy for staying within the prescribed ceiling. Figure 1a shows the temperature trajectory for a reference case and for ceilings of 2 °C and 3 °C. These trajectories incorporate the cooling effects of sulphate aerosols. Such effects are assumed to depend largely on local and regional air quality considerations and to be independent of global climate policy.

Some have suggested that we should be concerned with both absolute temperature change and the rate of temperature change[13]. To explore this possibility, we also examine situations in which an additional constraint is imposed on the two temperature scenarios. We limit the allowable increase during a single decade to 10% of the total allowable increase. That is, decadal temperature change is limited to 0.2 °C and 0.3 °C, respectively. Figure 1b shows that with a ceiling of 2 °C on absolute temperature change, there are decades during the twenty-first century where the limit on the rate of temperature change would be binding.

Figure 2a and c shows the price of the other two gases relative to that of carbon dioxide for temperature ceilings of 2 °C or 3 °C. It also shows the 100-year GWPs for each gas. We note that the relative prices vary over time. This is particularly so for CH_4. With its relatively short lifetime, a ton emitted in the early decades of the twenty-first century will have only a small effect on temperature in the late twenty-first century. As we approach the temperature ceiling, it becomes more worthwhile to reduce the emissions of a short-lived gas, relative to that of a long-lived gas. With a lifetime more nearly commensurate with that of CO_2, the price ratios for N_2O are less volatile. However, like CH_4, they are sensitive to the choice of ceiling. Limiting the temperature increase to 2 rather than 3 °C produces a different set of relative prices.

Figure 2b and d shows the implications of combining the temperature ceiling with a rate of change constraint. We note that the price ratios for CH_4 reflect what we observed earlier: the closer we are to the temperature constraint, the more valuable CH_4 becomes. This appears to be true whether the constraint is only

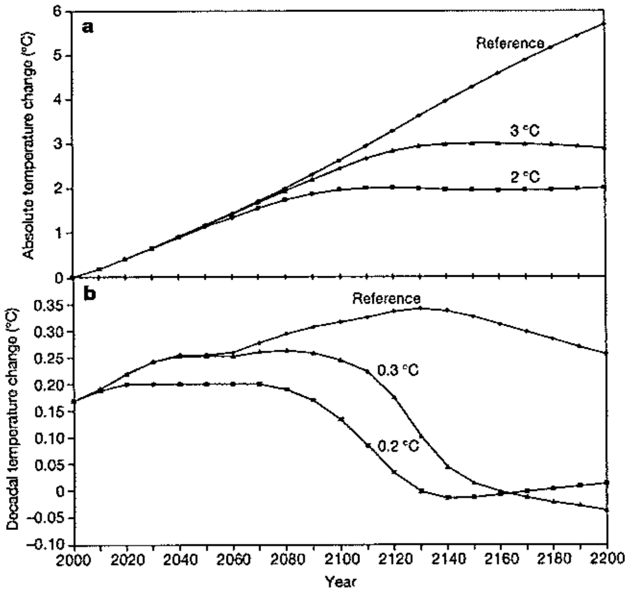

Figure 1 Absolute temperature change and decadal temperature change under alternative scenarios. For details regarding the composition of the reference case, see our website http://www.stanford.edu/group/MERGE/. **a**, Economically efficient temperature profiles for limiting absolute temperature change to 2 and 3 °C. **b**, Decadal temperature change when a rate of change constraint is also imposed. Here, we limit the allowable increase for a single decade to 10% of the total allowable increase.

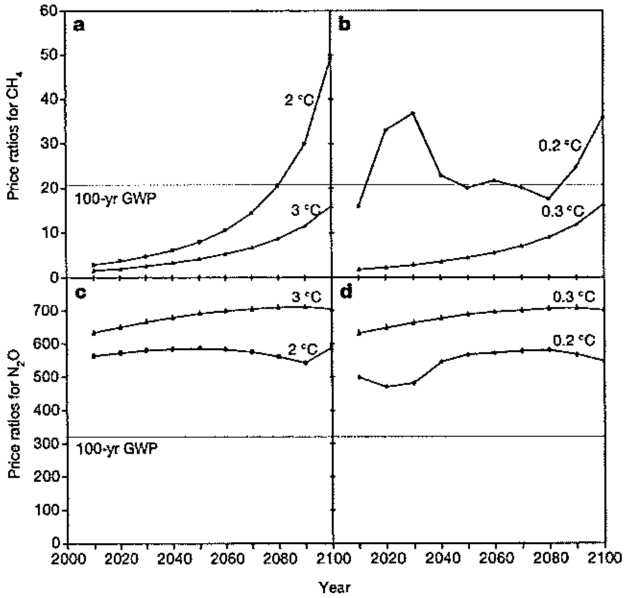

Figure 2 The prices of CH_4 and N_2O relative to that of CO_2 under alternative constraints on absolute and decadal temperature change. **a**, **c**, Prices of CH_4a nd N_2O relative to that of CO_2 when the ceiling is on absolute temperature change. **b**, **d**, The corresponding results when a rate of change constraint is added. GWP, global warming potential.

on absolute temperature, or on absolute and the decadal rate of temperature change.

Finally, to confirm the importance of the relatively short lifetime of CH_4 in determining its role in the portfolio of abatement measures, we conducted a hypothetical experiment in which the lifetime of CH_4 was doubled. As one would expect, we found that CH_4 prices rise more slowly as we approach a ceiling. This is because it takes more time for the impact of a reduction to be realized.

Earlier, we noted two problems with GWPs: the failure to incorporate damages and abatement costs, and the arbitrary choice of time horizon for calculating cumulative radiative forcing. Here we highlight two additional problems. GWPs assume that the trade-off ratios remain constant over time and are independent of the ultimate goal. Clearly, neither of these assumptions makes economic sense. The relative prices are a function of both the target and the proximity to the target. It is illogical to suppose that this is a case of "one size fits all"; yet this is precisely what is suggested by the IPCC in recommending the use of 100-year GWPs.

Unlike GWPs, the alternative we propose extends beyond purely physical considerations in calculating trade-offs among gases. Expectations about damages influence the choice of ceiling. Abatement costs influence the relative roles of the various gases in the portfolio of abatement actions. For example, we found that the higher the costs of abating CH_4, the larger the role of the other gases in a multi-gas reduction portfolio.

The approach also provides a clear definition of what constitutes an appropriate time horizon for the analysis. And it permits the necessary flexibility for the price ratios to vary both with the choice of and proximity to the target.

We believe that the proposed approach represents a more defensible way for making trade-offs among gases. Clearly, large uncertainties remain both with regard to damages (and hence, in what constitutes an appropriate ceiling) and abatement costs. Extensive sensitivity analysis is needed to determine which factors are most influential in determining the price ratios and thus where reducing uncertainty will have the highest pay-off. Nevertheless, uncertainty need not lead to paralysis. The issue is how to make the best near-term choices in the face of the many long-term uncertainties. As with other aspects of the climate debate, this requires a willingness to learn and make mid-course corrections. Price ratios can be designed on the basis of the best available information about both the physical system and the energy-economic system. As better information emerges, the price ratios can be modified accordingly. □

Received 7 June 2000; accepted 14 February 2001.

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Acknowledgements

We thank C. Gerlach and R. Parkin for research assistance. We have benefited from discussions with J. Aldy, J. Edmonds, L. Goulder, J. Reilly, R. Tol, J. Weyant, T. Wigley, L. Williams and T. Wilson. Funding was provided by EPRI.

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Coupled major and trace elements as indicators of the extent of melting in mid-ocean-ridge peridotites

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Rocks in the Earth's uppermost sub-oceanic mantle, known as abyssal peridotites, have lost variable but generally large amounts of basaltic melt, which subsequently forms the oceanic crust[1,2]. This process preferentially removes from the peridotite some major constituents such as aluminium, as well as trace elements that are incompatible in mantle minerals (that is, prefer to enter the basaltic melt), such as the rare-earth elements[3,4]. A quantitative understanding of this important differentiation process has been hampered by the lack of correlation generally observed between major- and trace-element depletions in such peridotites. Here we show that the heavy rare-earth elements in abyssal clinopyroxenes that are moderately incompatible are highly correlated with the Cr/(Cr + Al) ratios of coexisting spinels. This correlation deteriorates only for the most highly incompatible elements—probably owing to late metasomatic processes. Using electron- and ion-microprobe data from residual abyssal peridotites collected on the central Indian ridge, along with previously published data, we develop a quantitative melting indicator for mantle residues. This procedure should prove useful for relating partial melting in peridotites to geodynamic variables such as spreading rate and mantle temperature.

We studied minerals in 22 spinel peridotite samples, dredged from seven locations along the central Indian ridge (CIR) and its fracture zones. These samples are petrographically residual, lacking plagioclase and crosscutting magmatic veins. All samples are harzburgites except for one orthopyroxene-bearing dunite and two lherzolites. Clinopyroxenes (cpxs) have rare-earth-element patterns that are depleted in light rare-earth elements (LREEs), and all cover the most depleted range of the global abyssal peridotite spectrum[3,4]. Whereas the heavy rare-earth elements (HREEs) have a limited range in concentration (~2–10 times chondritic), the LREE abundances vary by more than an order of magnitude (Table 1).

To evaluate the relationships between major and trace elements, we selected all published global abyssal peridotites for which both mineral major-element and cpx trace-element data are available. This includes samples from three locations on the southwest Indian ridge (SWIR) and two on the American–Antarctic ridge (AAR)[3,4]. In addition, we used data from drill cores at Hess deep (East Pacific Rise)[5] and the MARK area (Mid-Atlantic Ridge near Kane fracture zone)[6], giving a reasonable sampling of global abyssal peridotite occurrences.

Second Generation Model non-CO2 GHG Modeling Framework

Francisco de la Chesnaye and Hugh Pitcher

Non-CO2 GHG Network
June 2001, Brussels

SGM Regions

- Annex I
  - United States
  - Canada
  - Western Europe
  - Japan
  - Australia/NZ
  - Former Soviet Union
  - Eastern Europe
- Non-Annex I
  - China
  - India
  - Middle East
  - Mexico
  - South Korea
  - Brazil
  - Rest of World

Production Sectors in SGM

SGM 98

1 Agriculture
2 Everything Else
3 Oil Production
4 Gas Production
5 Coal Production
6 Biomass
7 Nuclear Fuel
8 Electricity Production
  Oil-Fired
  Gas-Fired
  Coal-Fired
  Nuclear
  Hydro
9 Oil Refining
10 Gas Distribution

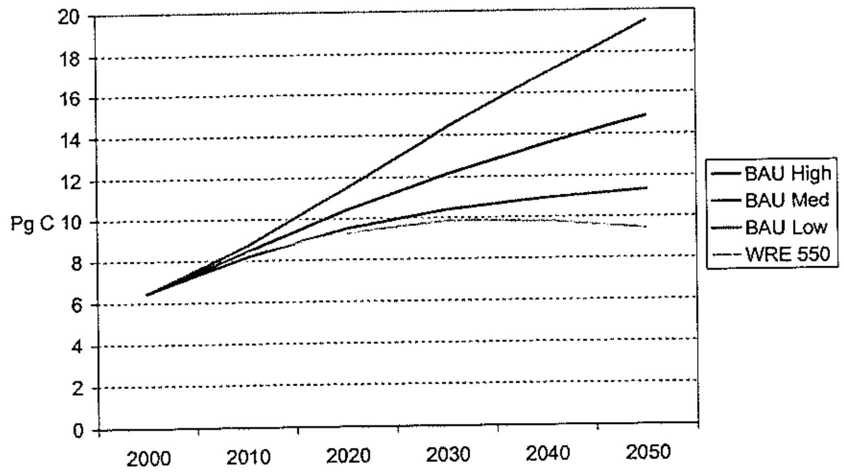
SGM 2000

1 Other Agriculture
2 Everything Else
3 Oil Production
4 Gas Production
5 Coal Production
6 Coal Products
7 Biomass
8 Electricity Production
  Oil-Fired
  Gas-Fired
  Coal-Fired
  Nuclear
  Hydro
9 Oil Refining
10 Gas Distribution
11 Paper and Pulp
12 Chemicals
13 Cement
14 Primary Iron and Steel
15 Primary Non-Ferrous Metals
16 Other Industry
17 Passenger Transport
18 Freight Transport
19 Grains and Oil Crops
20 Animal Products
21 Forestry
22 Food Processing

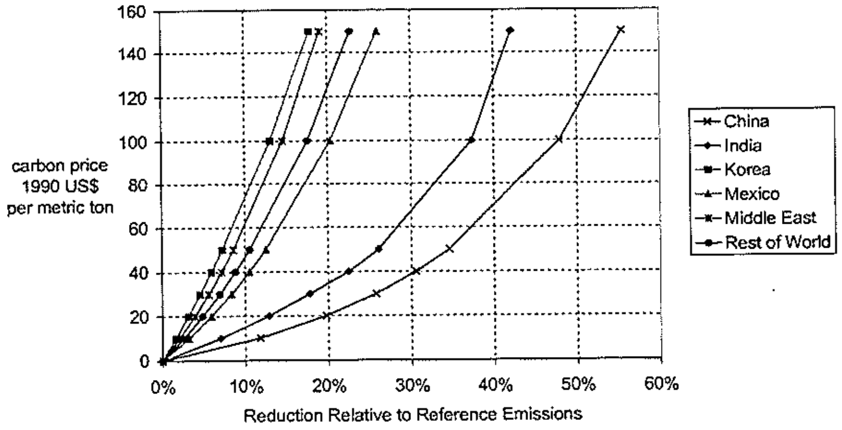
Key Characteristics

- Constant Elasticity of Substitution (CES)
- Fixed Coefficient (Leontief)
- Capital Stock
  - Five-year vintages
  - Industry specific
  - Elasticity of substitution of old capital is less than or equal to new capital
- Technical change parameters for all inputs

Global Carbon Emissions



Marginal Abatement Curves for Non-Annex I Regions

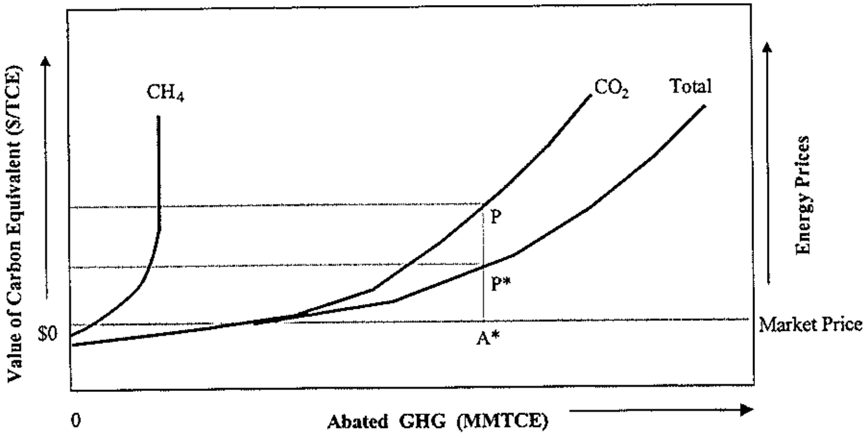


Approaches to combine / integrate non-CO2 GHG MACs with Energy Models

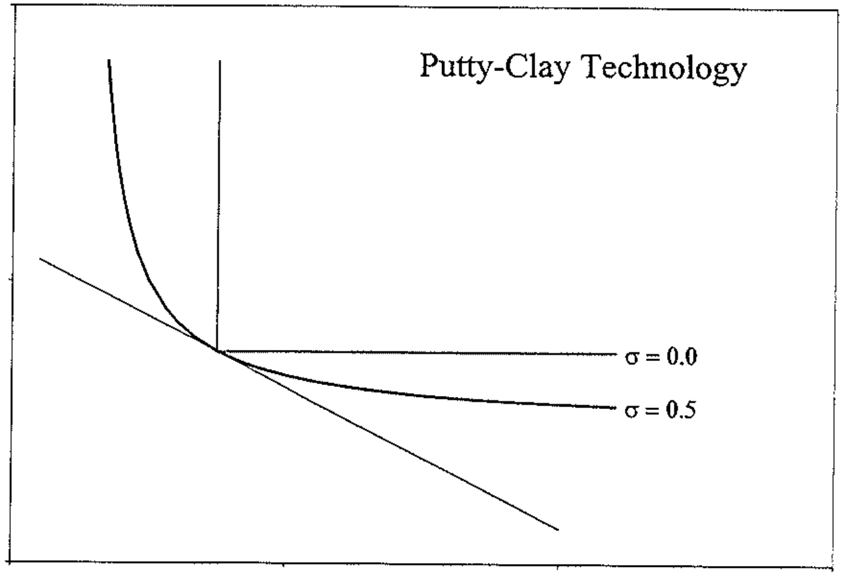
1. **Quick and Simple – Off-line addition**
   MAC results in $/TCE and cumulative reductions can be added to the supply curves from an energy model results in a spreadsheet to obtain one, total GHG abatement supply curve. From this, both price and quantity results can be obtained for different emission caps, target price, or both.
2. **Inclusion of reduced form equations from MACs**
   For both the MACs and the energy model supply curves, reduced form equations (regressions) can be developed. These can be used separately or added and then solved for specific energy or quantities.
3. **Endogenous non-CO2 MACs or cost parameters into energy model**
   Deconstructing the non-energy MACs to their appropriate sector or sub-sector cost identities and emission reduction potentials which are then used to modify the GHG emission coefficient in the energy model's production functions

Illustrative MACs for Methane and Carbon Dioxide

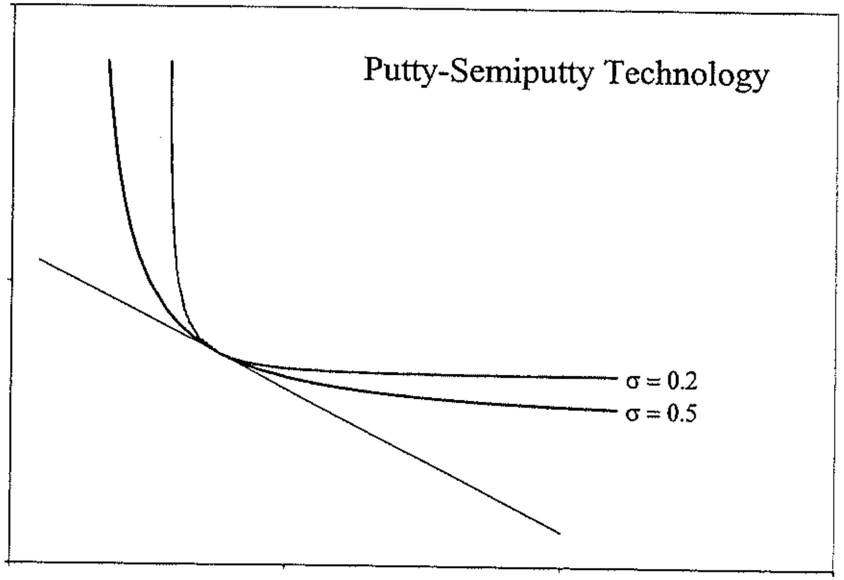
- benefits of multi-gas abatement strategy: lowers marginal and total costs of achieving reductions



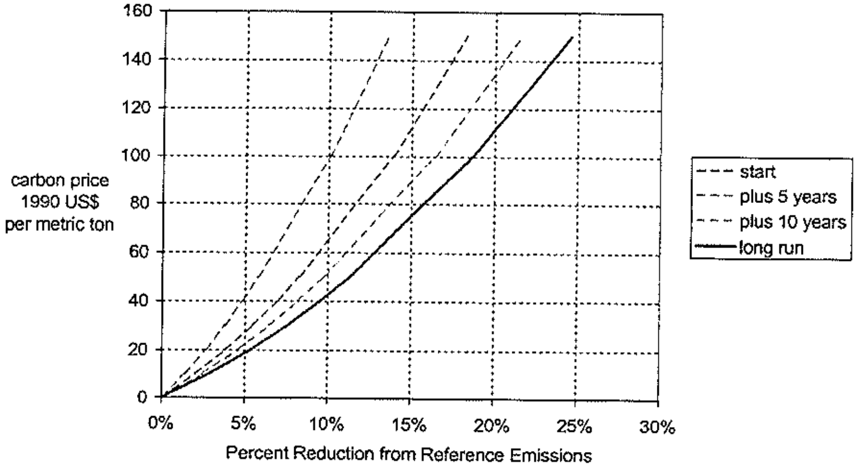
Putty-Clay Technology



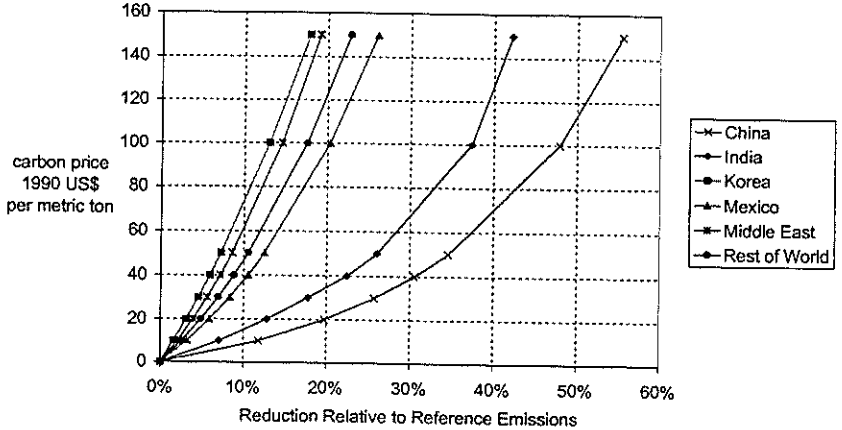
Putty-Semiputty Technology



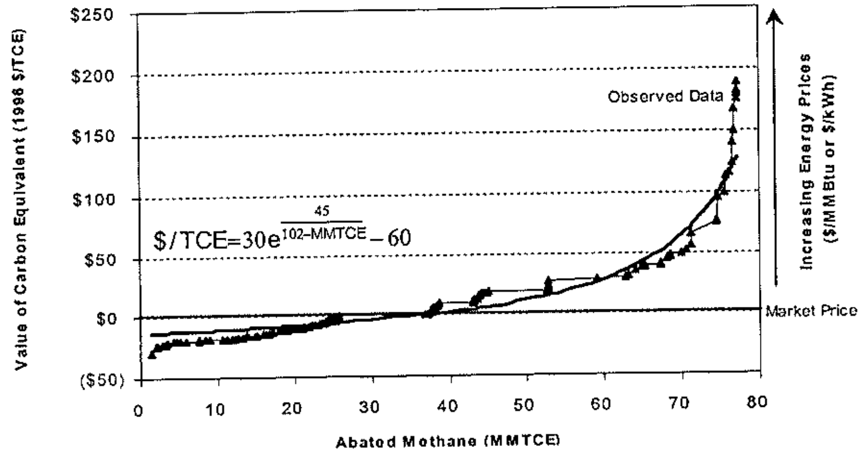
Marginal Abatement Curves
United States



Marginal Abatement Curves
for Non-Annex I Regions



U.S. Methane Marginal Abatement Curve for 2010 (major sources except ruminants)



$$\$/TCE=30e^{\frac{45}{102-MMTCE}}-60$$

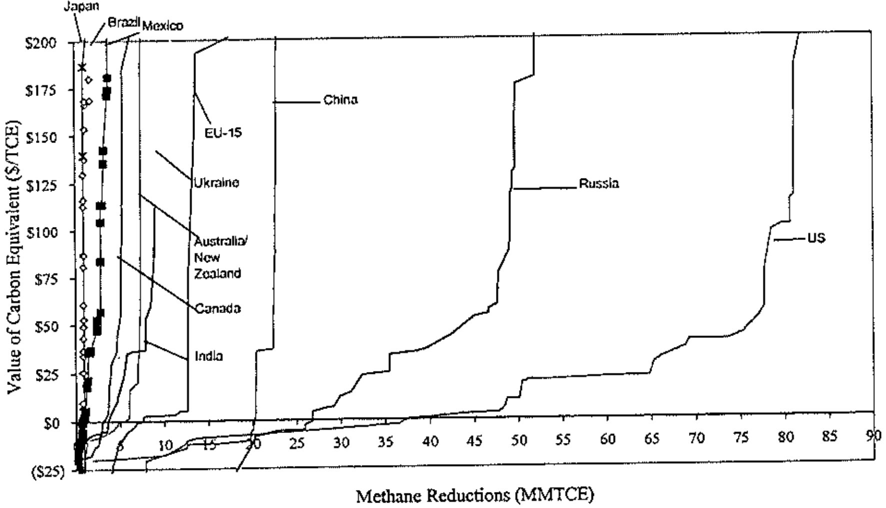
Source: *U.S. Methane Emissions 1990 – 2020: Inventories, Projections, and Opportunities for Reductions*, EPA, 1999

Science, 29 Oct 99: "*Costs of multi-greenhouse gas reduction targets for the U.S.*"

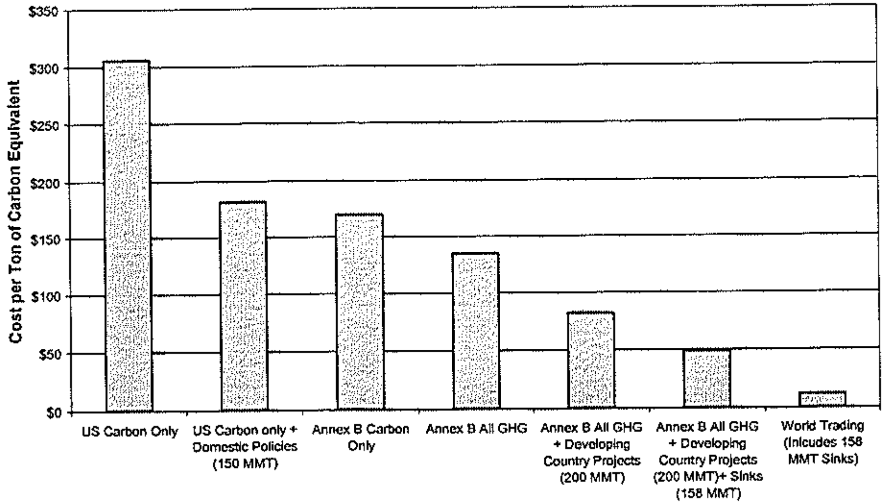
By K. Hayhoe, A. Jain, H. Pitcher, C. MacCracken, M. Gibbs, D. Wuebbles, R. Harvey, and D. Kruger

- Looked at CH_4 and CO_2 reductions
- Multi-gas approach to meet greenhouse gas emission targets can
  - increases the control options
  - can lower the national costs of meeting international agreements
- Based on EPA MACs, it's estimated that for short-term targets CH_4 can offset CO_2 reductions and reduce U.S. costs by more than 25% relative to strategies involving CO_2 alone.

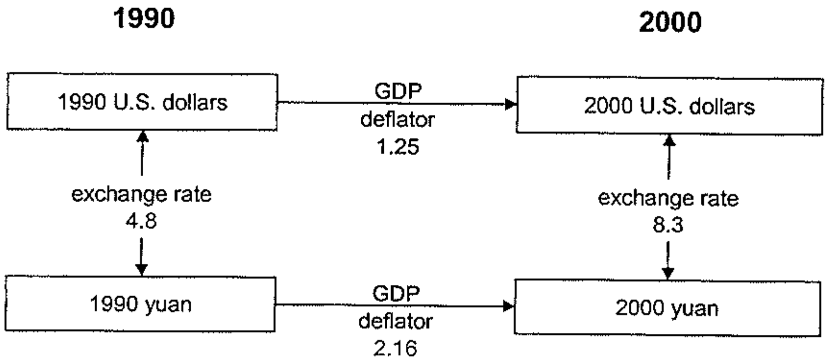
Methane Marginal Abatement Curves for Coal, Natural Gas, Landfills, & Manure Mgt, Select Regions - 2010 Baseline Emissions



Effect of Flexibility in Reducing Climate Mitigation Costs
based on SGM Carbon MACs + EPA non-CO2 & Sequestration MACs



Currency Conversion



1990

2000

1990 U.S. dollars

GDP
deflator
1.25

2000 U.S. dollars

exchange rate
4.8

exchange rate
8.3

1990 yuan

GDP
deflator
2.16

2000 yuan

Economic Potential of Greenhouse Gas Emission Reductions:

Comparative Role for Soil Sequestration in Agriculture and Forestry

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Paper prepared for presentation at DOE First National Conference on Carbon Sequestration, May 14-17, 2001, Washington D.C.

Economic Potential of Greenhouse Gas Emission Reductions: Comparative Role for Soil Sequestration in Agriculture and Forestry

Introduction

Society today stands at an important crossroads in terms of decision making. Increasingly, concerns are being expressed about the potential implications of the build-up in atmospheric concentrations of greenhouse gases. Alterations in agricultural and forestry (AF) land use and/or management provide a prospective way of mitigating net greenhouse gas (GHG) emissions. A number of AF practices are known to stimulate the absorption of atmospheric carbon or reduce GHG emissions at relatively modest cost with generally positive economic and environmental effects. Thus, an investigation of the comparative role for AF mitigation based practices in terms of economic implications appears in order.

AF practices partially involve sequestration and merit special consideration from that viewpoint. Sequestration involves capture of GHGs biologically or through industrial processes (e.g. by separating GHGs from fuels), then biological fixation or industrial injection into soils, aquifers, oceans or geological formations. AF sequestration generally refers to the absorption of carbon dioxide from the atmosphere through photosynthetic processes by plants or trees and subsequent fixation into soils, plants or trees. Thus, sequestration involves absorption of previously emitted gases and subsequent storage. Sequestration activities exhibit saturation where storage reservoirs fill up due to physical or biological capacity. They also generally store carbon in a potentially volatile state. For example, cutting down a forest and plowing the soil up for intensive farming quickly releases much of the sequestered carbon. Program costs involve development costs and operation costs as well as a maintenance cost to keep the carbon sequestered possibly even after saturation has been achieved. Comparison of the relevant role of sequestration considering these characteristics is another research need.

Objective

This paper examines the relative contribution of AF activities in an emission reduction program, focusing in part on the relative desirability of sequestration in forests and agricultural soils. The analysis will consider the effects of competition for land and other resources between AF activities and traditional production. In addition, analysis is done on the influence of saturation and volatility.

Approach

A two-pronged approach will be taken to the analysis of this question. First, following a paper by McCarl and Schneider (2001) we will use AF sector modeling to develop information on the marginal abatement cost curve describing the volume of GHG emission offsets at different farmer received carbon prices (i.e. market prices less brokerage fees and other transactions costs) ignoring saturation and volatility. That analysis will be done in the context of the total spectrum of U.S based AF responses to a net greenhouse gas mitigation effort. In particular, the role of AF sequestration efforts in the total portfolio of potential agricultural responses will be examined at alternative carbon price levels. The strategies considered are identified in Table 1. Definitions of those strategies and the characteristics of the underlying model are briefly summarized in the project description section below.

Second, following a paper by McCarl and Murray (2001), we will use a dynamic net present value framework to investigate the question of how a firm having to buy emission credits for the foreseeable future might factor in sequestration saturation and volatility to the prices it would be willing to pay for sequestration offsets. In turn, we will use the sector modeling methodology to investigate the implications for the role of soil carbon sequestration in a total AF mitigation effort.

Project Description -- Sector Modeling

The basic approach used for comparing the relative desirability of alternative mitigation strategies involves estimation of the amount of GHG net emission reduction supplied in the U.S. AF sectors and the choice of strategies under alternative carbon prices. The analytical framework employed had to be capable of looking at the induced adoption of the mitigation strategies listed in Table 1 as well as the complex interrelated nature of activities in the AF sectors. For example, use of a mitigation strategy could alter corn production and corn prices which in turn may impact exports, livestock diets, livestock herd size, and manure production as well as land allocation to biofuels and forests. The sector model captures these and other interactions. That model is a mathematical programming based, price endogenous sector model of the agricultural sector (ASM - McCarl et al., 2000b, Chang et al(1992), modified to include GHG emissions accounting by Schneider, 2000, and hereafter called ASMGHG) that is also expanded to include data from a forestry sector model (FASOM-Adams et al., 1996, Alig et al .,1998). ASMGHG depicts production, consumption and international trade in 63 U.S. regions of 22 traditional and 3 biofuel crops, 29 animal products, and more than 60 processed agricultural products. Environmental impacts include levels of greenhouse gas emission or absorption for carbon dioxide, methane, and nitrous oxide; surface, subsurface, and ground water pollution for nitrogen and phosphorous; and soil erosion.

ASMGHG simulates the market and trade equilibrium in agricultural markets of the U.S. and 28 major foreign trading partners. Domestic and foreign supply and demand conditions are considered, as are regional production conditions and resource endowments. The market equilibrium reveals commodity and factor prices, levels of domestic production, export and import quantities, GHG emissions management strategy adoption, resource usage, and environmental impact indicators. ASMGHG was then repeatedly solved for carbon prices ranging from $0 to $500 per ton of carbon equivalent. The 100-year global warming potentials of 1 for carbon dioxide, 21 for methane, and 310 for nitrous oxide were used to convert methane and nitrous oxide emissions to carbon dioxide equivalency. In turn the estimates were multiplied by 12/44 to convert from a carbon dioxide equivalent to a ton carbon equivalent basis.

Mitigation Strategy Overview

Readers are likely to be interested in the nature of the mitigation strategies and assumptions therein. A brief discussion of each item in Table 1 follows.

Afforestation and Timberland Management:

Forest based carbon sequestration can be stimulated by afforestation of agricultural lands, increasing rotation length, or changing management intensity through improved silvicultural practices. The data for the forest sequestration increase were developed using the Forest and Agricultural Sector Optimization Model (FASOM, Adams et al., 1996 , Alig et al .,1998). FASOM was repeatedly solved under alternative prices ranging from $0 to $400 per ton of carbon equivalents. For each FASOM solution, we computed and exported into ASMGHG the average annual sequestration rate over the first 30 years of the program (2000-2030) and the associated net land transfer from agriculture to forestry. The underlying data reflect regionally specific conversion of crop and pasture lands to and from trees as well as rotation and management changes.

Biofuel Production:

Offsets of GHG emissions from fossil fuel usage were examined by considering substitution of biofuels for fossil fuels. In particular, we incorporated poplar, switchgrass, and willow for fueling electrical power plants and cornstarch for conversion into ethanol. Information on the production and conversion alternatives were drawn from a joint U.S. EPA/DOE/USDA/OSTP study of biofuels as elaborated on in McCarl et al., 2000a. The emission savings were computed on a BTU basis assuming biomass substitution for coal in power plants and ethanol substitution for gasoline. In estimating emissions offsets the emissions accounting was the savings from not using traditional fossil fuels less the emissions from the energy involved in raising, hauling and processing the biofuels.

Crop Fertilization Alteration:

Nitrous oxide emissions are a byproduct of nitrogen fertilization. In turn, nitrogen fertilization also influences carbon sequestration rates. Altered fertilization practices were examined using data on crop yield response and resultant carbon sequestration rates. These data were developed via a crop simulation model as described under the tillage section below. The Intergovernmental Panel on Climate Change (IPCC) good practice inventory guidelines were used to estimate nitrous oxide emissions per unit fertilizer applied. These formulas basically had about 1.25 percent of applied nitrogen being released as nitrous oxide.

Crop Input Substitution:

A number of the inputs used in crop production are fossil fuel based or embody substantial GHG emissions in their manufacture. Carbon content estimates including upstream manufacturing carbon emissions were incorporated in the analysis for diesel, gasoline, natural gas, electricity, and fertilizers using the IPCC good practice guidelines. Thus, changes in crop mix, crop management, livestock numbers, etc. alter input use and resultant emissions patterns.

Crop Mix Alteration:

Not all crops emit equally because of differences in fertilizer applied, tillage practices, chemical inputs, harvest requirements, irrigation intensities, and post harvest processing among other factors. In this study, we included both direct emissions from these activities and indirect emissions from the involved inputs. As a result, carbon dioxide, nitrous oxide, and methane emissions are affected by crop mix choices.

Crop Tillage Alteration:

Energy intensity and soil carbon content are sensitive to choice of tillage method. The analysis considered implications of using conventional tillage, minimum tillage, and no tillage. Emission estimates for soil carbon increments were derived from a 63 region, 10 crop, 5 soil type crop simulation study using the EPIC crop growth simulator (Williams et al., 1989). The carbon sequestration rates pertaining to tillage changes were average results for the first 30 years of the program (2000-2030) adjusted to be consistent to an annual 75 million metric tons (MMT) from treating all U.S. croplands for sequestration as developed in Lal et al. (1998 who actually developed a range from 75 to 200+ MMT). Estimates were also developed on emissions from fossil fuels used to carry out the alternative tillage systems as well as applying an altered mix of chemical inputs based on USDA Natural Resource Conservation Service production budgets.

Grassland Conversion:

Reversion of cropland back to grassland is another mitigation strategy considered. Such a reversion generally increases soil carbon and, in addition, affects nitrous oxide emissions by displacing fertilizer used in crop production.

Irrigated/Dry Land Conversion:

Alterations in the allocation of land between irrigated and dry land usages affects soil carbon, nitrous oxide emissions, and fossil fuel use needed for water delivery and other crop production and requirements.

Livestock Management:

Methane emissions per unit product produced may be influenced by giving growth hormones to animals or by increasing the use of grain relative to forage in feeding. Growth hormone based alternatives were incorporated based on EPA data. Feed substitution was also embodied in livestock production system choice as discussed below.

Livestock Herd Size Alteration:

Livestock produce methane and nitrous oxide generally as a function of the total size of the livestock herd through manure and ruminant enteric fermentation. Thus a simple mitigation alternative is to cut the size of the total herd.

Livestock Production System Substitution:

Mitigation may be pursued through the substitution of livestock production systems for one another. In the case of beef cattle, slaughter animals can be produced using either stocker or feedlot operations. The relative GHG emission rate varies across these alternatives, i.e., feedlot production has lower per unit emissions.

Manure Management:

Manure is a source of methane and nitrous oxide. The manure handling system can influence emissions. For example methane emissions are greater the more water is involved in the system but methane recovery systems can also be employed. For this analysis, we incorporated data on methane emissions from liquid manure handling alternatives by region and livestock type based on EPA data.

Rice Acreage:

Decomposition of plant material in flooded rice fields leads to methane emissions. While alternative management systems may affect the amount of methane released, no consistent data were available at this point. Thus, the only rice related mitigation alternative examined here involves reductions in acreage.

Results – Sector Modeling

Scientific evidence and the number of inquiries regarding AF GHG mitigation are growing rapidly. The data underlying this study, while the best available to us as at this point in time will be old and obsolete tomorrow and could even be improved by substantial efforts today. Consequently, we will not concentrate on specific empirical results. Rather we will highlight a set of general findings, that we believe are highly relevant to consideration of the appropriate role for AF sequestration and to the extent possible, that rise above the flaws in the underlying data.

AF Provides Cost Effective Emissions Offsets Particularly Through Sequestration.

Figure 1 shows the amount of carbon offsets gained at carbon prices ranging from $0 to $100 by broad category of strategy. Note in those results that up to 326 MMT carbon equivalent can be offset by AF means (Table 2). Low cost strategies involve foremost soil carbon sequestration and to some extent afforestation, fertilization, and manure management. To place these costs in perspective one should note Weyant and Hill's (1999) report of a multi model study of non-agricultural Kyoto compliance costs sponsored by the Energy Modeling Forum (EMF). Across that EMF set of studies, abatement costs vary with assumptions on emissions trading and because of different baseline emissions scenarios across models. For the case of the United States with carbon emissions trading among Annex I regions, primarily the developed industrial countries along with eastern Europe and the former Soviet Union, abatement costs were generally in the range of $50 to $100 per metric ton of carbon but ranged as high as $227. See MacCracken et al. (1999) for an example of the range of abatement costs that can be derived within one model. Marginal abatement costs are much higher without international trade in carbon emissions rights.

A Portfolio of AF Strategies Seems to be Desirable.

Today many different GHG emission (GHGE) mitigating agricultural strategies are being considered and often individually advocated. Our results show that a portfolio solution appears to be appropriate. Figure 2 shows the total response of mitigation over the total range of carbon prices. The results show a role for biofuels, forests, agricultural soils, methane, and nitrous oxide based strategies. The figure also shows that different strategies take on different degrees of relative importance depending on price level. While soil carbon sequestration peaks at around $50 per ton, biofuel offsets are not competitive for prices below $60 per ton. Reliance on individual strategies appears to be cost increasing. For example reliance solely on agricultural soil carbon (Figure 3 – economic potential line) means it would cost $30 to achieve 60 MMT while consideration of the total portfolio leads to a cost below $15 per ton (from table 2).

Difference Between Technical, Economic, and Competitive Economic Potential

Many of the estimates for the potential of selected strategies ignore cost and resource competition. Lal et al., 1998, for example compute a total agricultural soil carbon (ASC) potential, but do not specify the cost of achieving such a potential level of sequestration. Figure 3 displays ASC technical, economic, and competitive economic potential. The total technical potential in this case is 75 MMT annually but under reliance only on ASC this does not occur even for prices as high as $500 per ton. At lower prices substantially less carbon is sequestered. Furthermore, when ASC strategies are considered simultaneously with other strategies, the carbon price ($500 per ton) stimulates at most 64 MMT or 87% of maximum potential while sequestration falls to 50 MMT (67%) at a $200 price because other strategies are more efficient at that payment level.

Concentration on Single Strategies Can Cause Leakages in Other Categories.

Figure 4 shows the relationship between the increase in forest based offsets and emissions in the rest of the AF sector. The results indicate for an afforestation accounting only case that the anticipated gains in forestry are in some cases augmented and in other cases offset by emissions in the rest of the AF sectors. This more complex relationship occurs because land moving out of agriculture into forests places pressure on the remaining cropland, stimulating production intensification in terms of irrigation, tillage and fertilization. Thus, we find more emission intensive technologies on fewer acres of agricultural cropland. Leakage also occurs in forestry, where the underlying FASOM results show up to a 50 percent offset, largely from traditional forestland moving into agriculture or reducing management intensity (McCarl (1998) shows such results).

Mitigation Based Offsets are Competitive With Food and Fiber Production.

Achieving net GHGE offsets requires that AF operations change. Many of the strategies divert land or inputs away from crop or possibly timber production. On the agricultural side, Table 2 shows that crop prices generally rise the more mitigation is undertaken while production falls. Exports are also strongly affected. On the forestry side, afforestation can cause price declines if the rotation of harvested stands lengthens. At higher carbon prices, increasing land competition among strategies leads to increased afforestation and biofuel usages of croplands but reduced agricultural soil sequestration.

Adopting Mitigation Strategies Impacts the Environmental

Many of the proposed agricultural mitigation actions (tillage intensity reduction, manure management, land retirement etc.) have long been discussed as strategies which simultaneously improve environmental quality. Consequently, one may expect benefits in terms of erosion control, runoff etc. which are created simultaneously with emissions abatement. Table 2 shows changes in a few selected environmental parameters as carbon equivalent prices increase. For the most part, these results confirm declining rates of nitrogen and phosphorous runoff as well as reduced erosion. However, reliance on biofuels causes the environmental co-benefits largely stabilize at prices around $200 per ton.

Project Description – Saturation and Volatility

Yet another question regarding sequestration involves the way a decision maker might view AF sequestration relative to say an emissions reduction given the opportunity to buy one or the other. To investigate this question we use net present value analysis to find the breakeven carbon price one would be willing to pay for nominally equal cost and carbon potential sequestration and emission offset opportunities. In doing this we will follow the work of McCarl and Murray (2001).

The basic procedure we will use involves the evaluation of the price for carbon that renders the net present value of a stream of carbon equivalent offsets equal to program costs. Specifically, we solve the following equation for the breakeven carbon price p:

$$\sum_{t=0}^{T}(1+r)^{-t}\,p\,E_t=\sum_{t=0}^{T}(1+r)^{-t}C_t,$$

where r is the discount rate -- assumed to be 4%, T the number of years in the planning horizon - assumed to be 100, p a constant real price of emission offsets, E_t the emissions offset in year t, and C_t the cost of the emissions offset program in year t. Then by comparing prices for different possibilities we can determine the effect of saturation and volatility.

Results – Saturation and Volatility

For illustrative purposes we will consider three hypothetical cases that allow comparison of relative carbon prices by opportunity. McCarl and Murray (2001) consider many more.

Case A: Emissions offset - Suppose an emission offset can be obtained which annually offsets one unit of carbon for the full 100 years at a cost of 1 monetary unit (e.g. one dollar) per year. The breakeven price for this is one unit ($1 per unit carbon).

Case B: Saturating Agricultural Soil Carbon - Consider an agricultural soil carbon case that sequesters an average amount of one carbon unit per year but then saturates after 20 years consistent with the findings in West et al. If payments stop after 20 years, the carbon preserving practice ceases, releasing (volatilizing) the carbon into the atmosphere over the next 3 years. Given these characteristics we find a breakeven price of 2.64 units. Alternatively, if the practice is subsidized for the remaining 80 years, this price amounts to 1.80. This implies that the saturating/volatile soil carbon is worth between 36 percent and 55 percent of the emissions offset.

Case C: Forest carbon - Carbon in forests will saturate after trees reach maturity in about 80 years. The sequestered carbon is volatile because the trees may be harvested releasing soil and standing tree carbon, but also placing carbon into products that provide longer term storage or fuel offsets. A forest reserve that sequesters a unit for 80 years costing one monetary unit has a break-even price of 1.02 or just a 2 percent discount. A 20-year harvest pattern for pulpwood stands with fuel credits counted leads to prices in the range of 65-70% of emissions while a 50 year saw timber stand comes out at 85-87%. Other cases in McCarl and Murray (2001) range as low as 51%.

For illustrative purposes we then reran the sector-modeling framework but multiplied the price applied to carbon from tillage changes on agricultural soils by 0.50 and that from forests by 0.75. In turn the total portfolio of options (Figure 5) chosen shifted with agricultural soil and forestry shares declining. The agricultural soil maximum fell by about 55 percent while the forestry adjusted down by 48 percent.

Application

Agricultural and forest carbon sequestration are important components of a possible total societal response to a greenhouse gas emission reduction initiative. Our analysis shows that determination of their appropriate role depends upon the carbon price. At low prices, agricultural soil sequestration appears highly competitive but saturation and volatility will likely lead to price discounts. Forest based sequestration and biomass offsets gain in importance at higher carbon prices.

Future Activities

More work is planned along these directions to bolster the data underlying the sector model and further investigate the role of sequestration in a world where carbon prices change over time.

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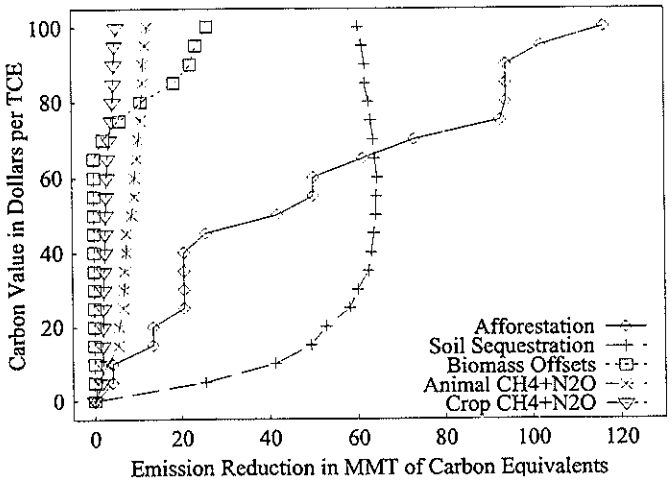


Figure 1 Agricultural Mitigation Potential at $0 to $100 per Ton Carbon Equivalent Prices

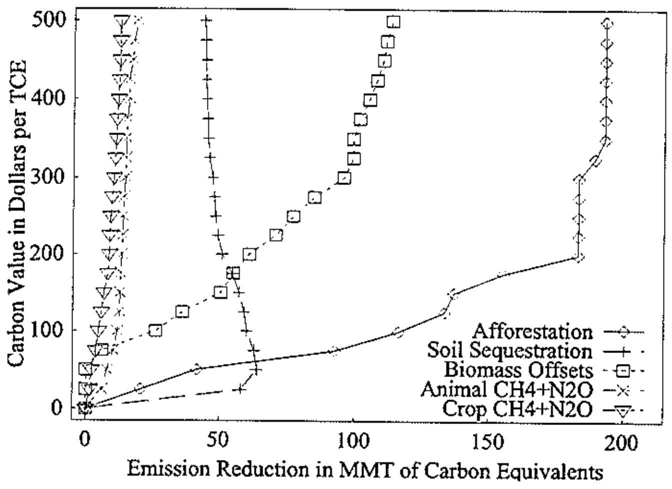


Figure 2 Agricultural Mitigation Potential at $0 to $500 per Ton Carbon Equivalent Prices

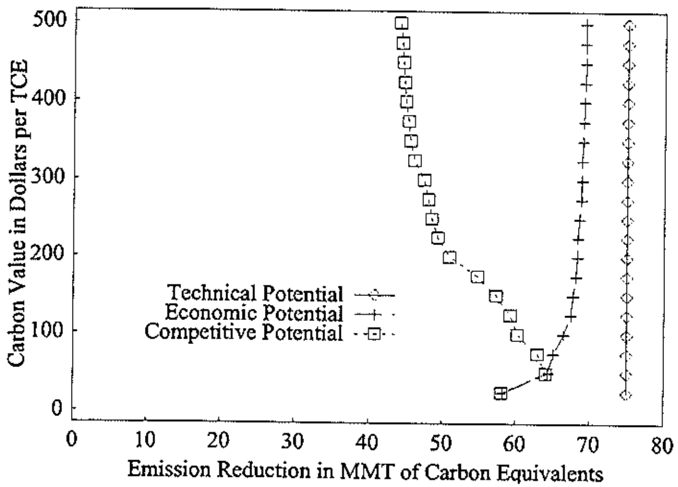


Figure 3 Agricultural Soil Carbon, Technical, Sole Source Economic and Competitive Economic Response

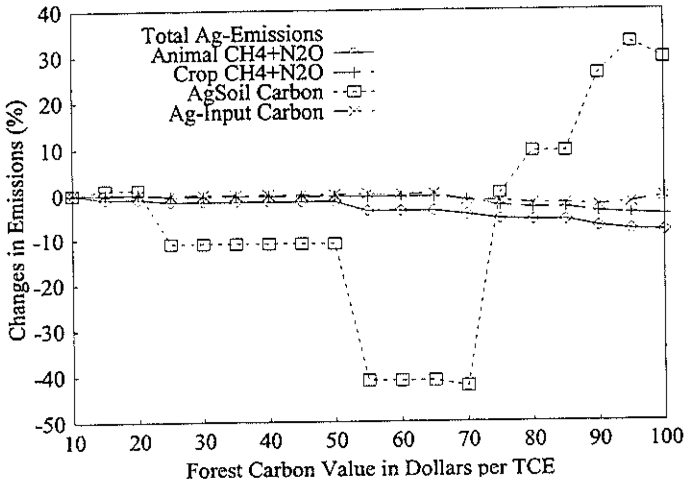


Figure 4 Gross and Net Mitigation of Sole Reliance on Forestry Related Strategies

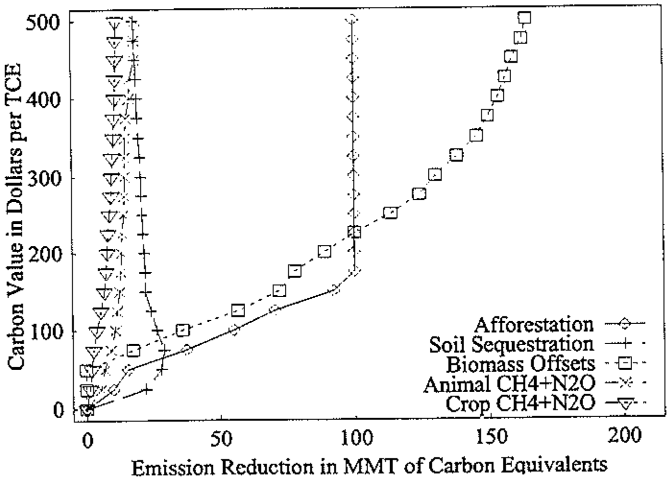


Figure 5 Agricultural Mitigation Potential at $0 to $500 per Ton Carbon Equivalent Prices When Saturation and Volatility are Accounted for by Price Discounts

Table 1 Mitigation Strategies Included in the Analysis

Strategy	Basic Nature	Greenhouse Gas Effected		
		CO2	CH4	N2O
Afforestation / Timberland Management	Sequestration	X		
Biofuel Production	Offset	X	X	X
Crop Mix Alteration	Emission, Sequestration	X		X
Crop Fertilization Alteration	Emission, Sequestration	X		X
Crop Input Alteration	Emission	X		X
Crop Tillage Alteration	Emission	X		X
Grassland Conversion	Sequestration	X		
Irrigated /Dry land Conversion	Emission	X		X
Livestock Management	Emission		X	
Livestock Herd Size Alteration	Emission		X	X
Livestock Production System Substitution	Emission		X	X
Manure Management	Emission		X	
Rice Acreage	Emission		X	

Table 2 Results at Selected Carbon Price Scenarios

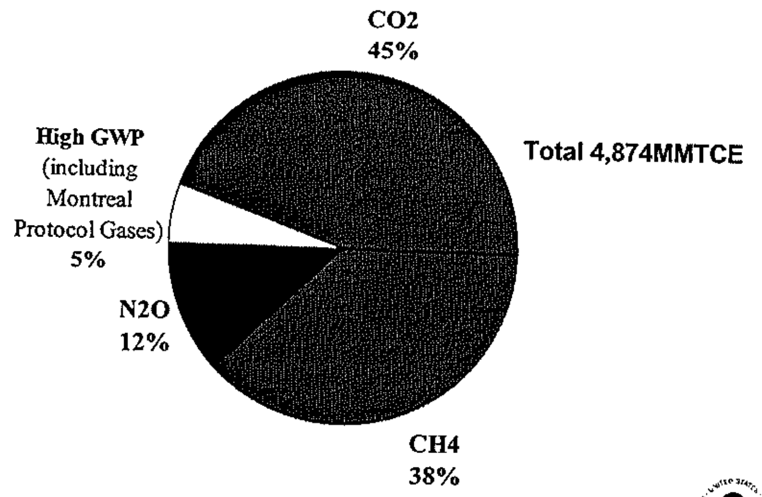
Category Sub-Category	Unit	Carbon Equivalent price in $/metric ton C					
		10	20	50	100	200	500
Strategy							
Soil Carbon	1000 TCE	52,771	63,148	60,341	51,060	44,967	44,163
Afforestation	1000 TCE	13,445	20,619	116,361	183,191	192,893	192,947
Biomass	1000 TCE	0	0	26,154	61,020	105,045	113,456
Fossil Fuel Ag-Inputs	1000 TCE	4,285	6,696	10,156	12,433	14,971	15,807
Livestock Related	1000 TCE	5,674	7,390	12,462	13,989	16,547	19,443
Crop Non-Carbon	1000 TCE	1,959	2,427	5,304	9,081	12,239	13,003
GHGE Mitigation							
C	MMTC	71.26	91.81	216.14	309.3	356.7	364.61
CH4	MMTCH4	0.78	1.02	1.89	2.39	3.07	3.50
N2O	MMTN2O	0.04	0.05	0.09	0.14	0.18	0.20
CE	MMTCE	79.11	101.98	235.31	334.11	389.09	400.94
Market Effects							
Production	Fisher Index	99.81	98.74	91.20	77.77	67.73	65.37
Prices	Fisher Index	100.65	102.41	118.81	155.93	222.07	261.01
Ag-Sector Welfare	Billion $	-0.45	-0.90	-5.65	-15.33	-29.79	-35.05
Net Exports	Fisher Index	99.17	96.11	74.26	35.33	25.58	22.81
Other Externalities							
Nitrogen pollution	% Change	2.10	3.63	-6.26	-21.47	-34.65	-37.40
Phosphorous pollution	% Change	-43.35	-49.02	-52.93	-53.61	-58.15	-60.54
Erosion	% Change	-35.04	-41.28	-49.70	-55.62	-61.23	-63.27

Some thought to stimulate discussion on The Way Forward

Francisco de la Chesnaye
U.S. Environmental Protection Agency

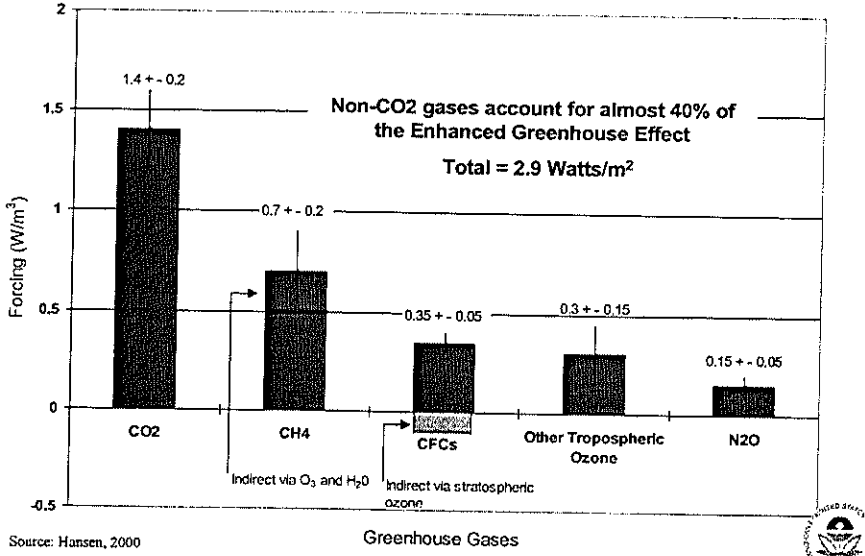
Non-CO2 GHG Network
June 2001, Brussels

Global GHG Emission in 2000



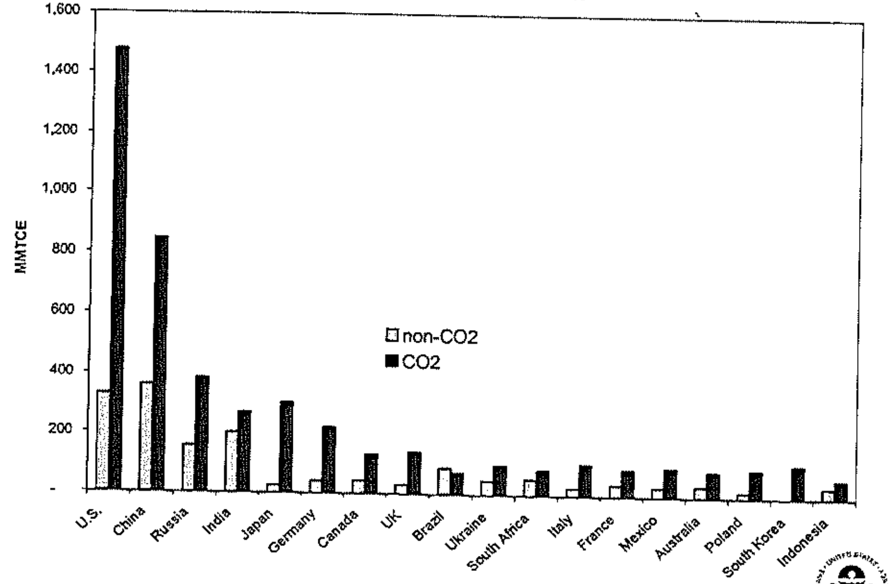
Source: SRES, 2000

GHG Climate Forcings



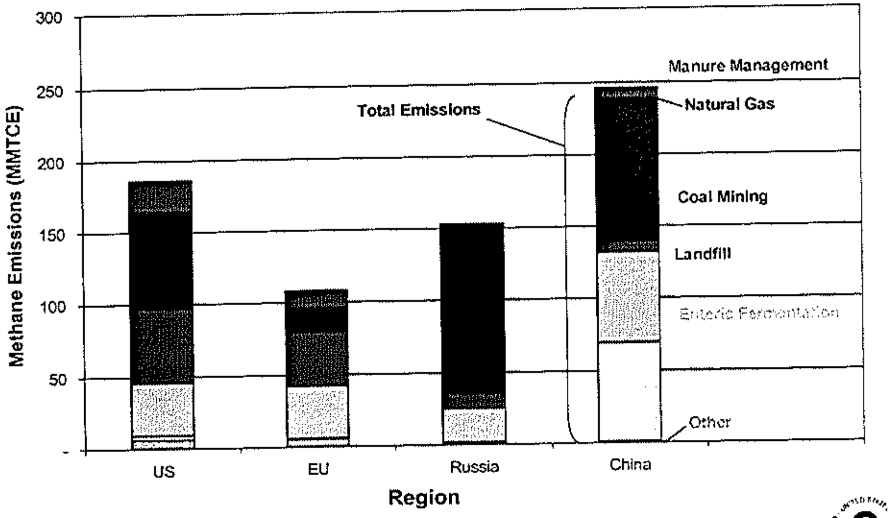
Source: Hansen, 2000

1997 GHG Emissions of top 20 countries



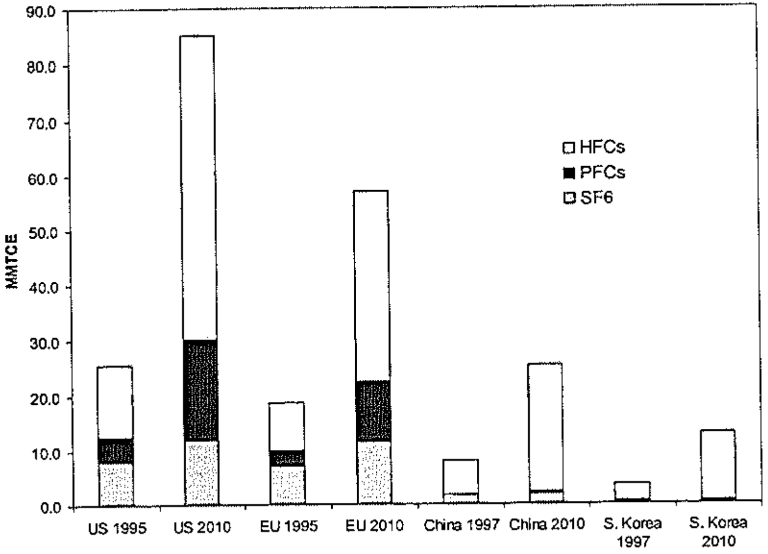
Source: National Communications, US Country Studies, ALGAS Series, EPA Estimates

Methane Emissions by Sector for Select Regions Based on 2010 Baseline Emissions



Source: Compiled in EPA Reports.

High GWP (F gases) 1995/97 & 2010

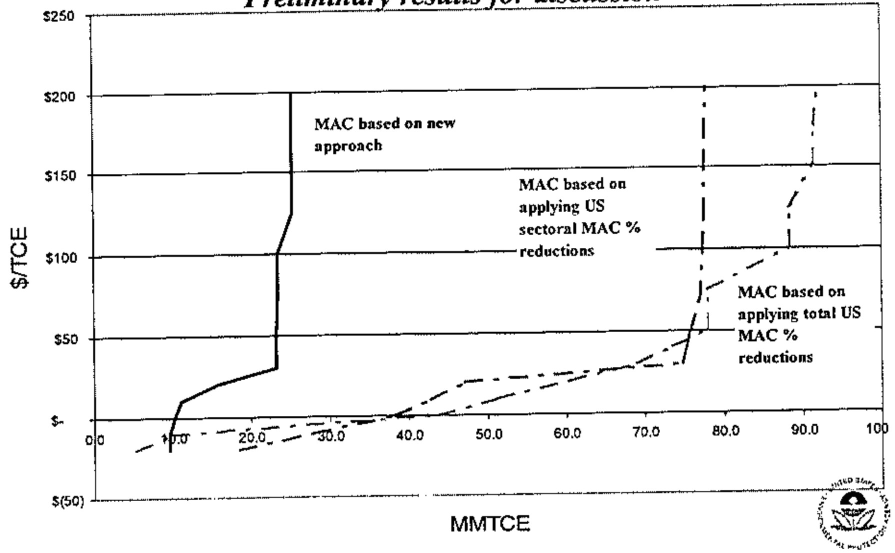


Source: EPA Reports.

China Methane MAC for 2010

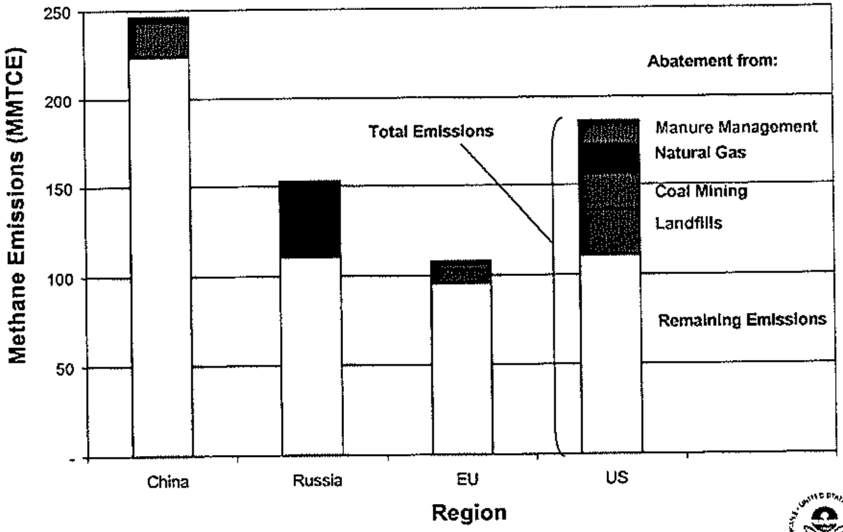
Modeled vs Applying US Percent Reductions

Preliminary results for discussion



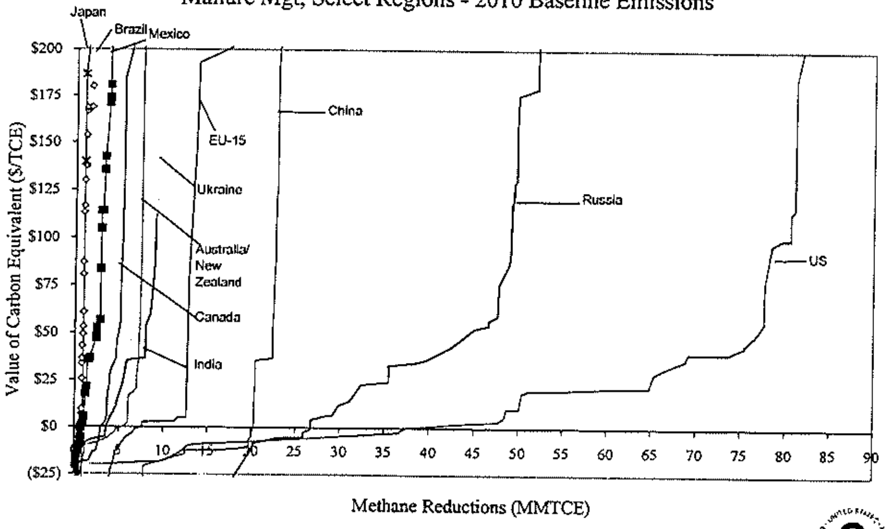
Methane Reductions by Sector Based on 2010 Baseline Emissions and a Carbon Price of $50/TCE

Preliminary results for discussion

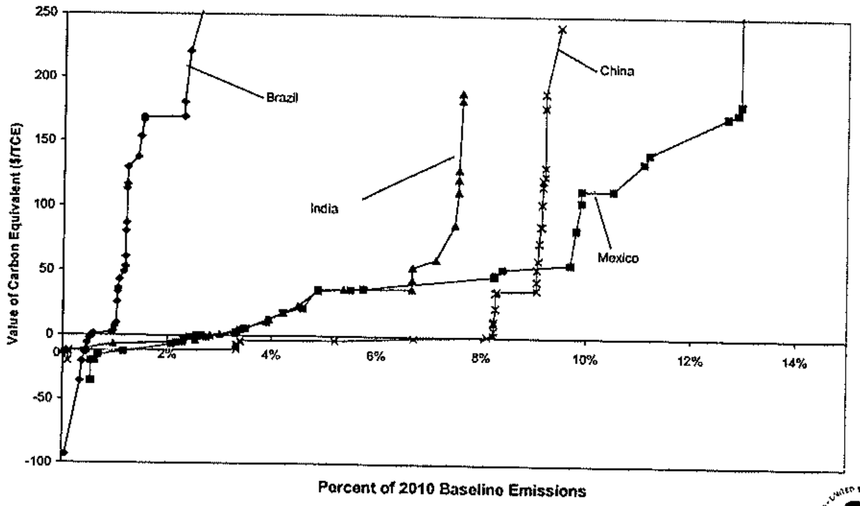


Source: EPA Reports.

Methane Marginal Abatement Curves for Coal, Natural Gas, Landfills, & Manure Mgt, Select Regions - 2010 Baseline Emissions



Percent of 2010 Baseline Methane Emissions Abated for Select Developing Countries



Difference in Modeling Approach

Est for 2010 **Marginal Abatement Curves at $50/TCE**

Methane in MMTCE

Country	Country Specific Reductions	Applying U.S. Percent MAC to Baselines	Difference
EU 15	12	32	20
Australia & New Zealan	8	15	7
Japan	1	3	2
Canada	4	8	4
Russia	32	48	16
Ukraine	4	12	8
Eastern Europe	16	28	12
China	23	78	55
India	9	38	29
Brazil	2	23	21
South Korea	0	23	22
Mexico	3	8	5
TOTAL	116	314	199

Note: analyses done with a 15% discount rate and a 40% tax rate 730 MMTCO2E

International non-CO2 MAC results

Region *Russia*
YEAR 2005

DR = 4%; TR = 0%

	Emissions Reduction Values									
$	(20)	$0	$10	$20	$40	$50	$75	$100	$150	$200
MMTCE	0.2	25.6	28.1	33.7	42.7	45.1	46.2	48.2	48.9	51.2
%	0.1%	17.3%	19.0%	22.8%	28.9%	30.5%	31.2%	32.6%	33.1%	34.6%

DR = 10%; TR = 40%

	Emissions Reduction Values									
$	(20)	$0	$10	$20	$40	$50	$75	$100	$150	$200
MMTCE		21.2	25.9	26.0	33.8	34.0	39.3	46.1	48.3	48.5
%		14.3%	17.6%	17.6%	22.9%	23.0%	26.6%	31.2%	32.6%	32.8%

DR = 15%; TR = 40%

	Emissions Reduction Values									
$	(20)	$0	$10	$20	$40	$50	$75	$100	$150	$200
MMTCE		20.8	25.8	26.0	30.2	30.9	36.5	38.4	47.1	48.4
%		14.1%	17.5%	17.6%	20.4%	20.9%	24.7%	26.0%	31.9%	32.7%

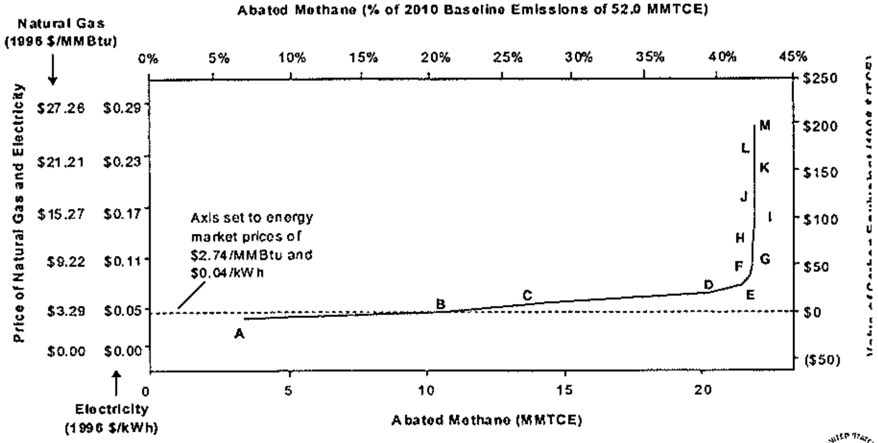
DR = 20%; TR = 40%

	Emissions Reduction Values									
$	(20)	$0	$10	$20	$40	$50	$75	$100	$150	$200
MMTCE		20.8	25.8	26.0	30.2	30.9	36.5	37.5	47.0	48.3
%		14.1%	17.5%	17.6%	20.4%	20.9%	24.7%	25.3%	31.8%	32.7%

Modeling Teams including non-CO2 GHG in analyses

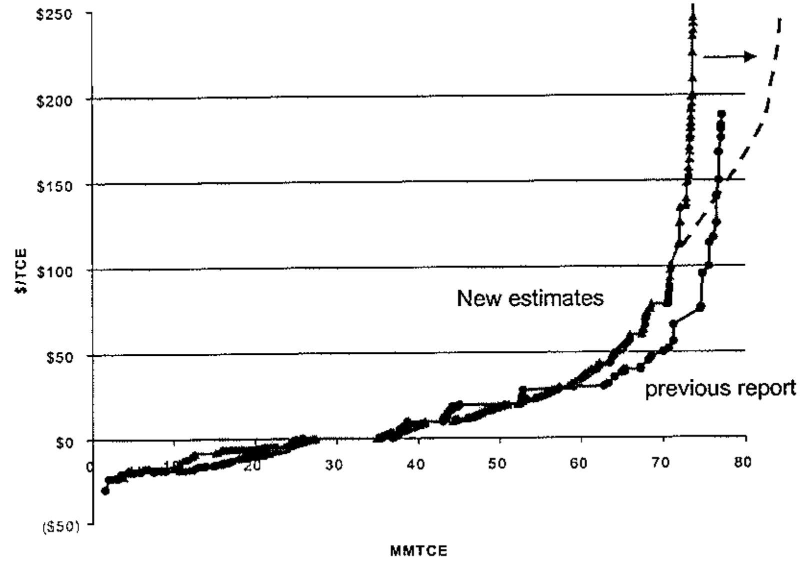
- MIT w/ EPPA model, 1999
- ABARE w/ GTEM, 1999
- PNNL, Univ. of IL, EPA w/ SGM, 1999
- EPRI w/ MERGE, 2001
- CICERO Norway w/ POLES model, 2001
- EC DG Environment w/ various, 2001
- IAE Japan w/ GRAPE model, 2001
- Argonne Nat Lab w/ AMIGA, current

Marginal Abatement Curve for Methane Emissions from Landfills in 2010



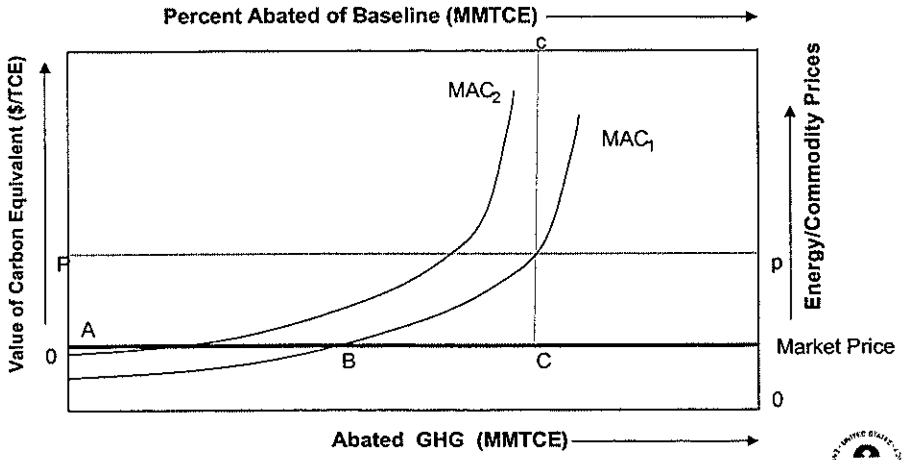
Source: EPA,

U.S. Methane Marginal Abatement Curve for 2010 Effect of including new technologies



The use of MACs for non-CO$_2$ GHG Policy Analyses or: Various Interpretations of a Four Axes MAC

Illustrative non-CO$_2$ MAC



Use of MACs for non-CO_2 GHG Policy Analyses

1. Sector-specific emission limit or cap
2. Price Instruments and effects (credits, subsidies, taxes and effects of cross-sector caps)
3. Regulatory Standards
4. Sector Opt-in
5. Offsets
6. Voluntary Programs

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Office of Air and Radiation, Methane & Sequestration Branch
1200 Pennsylvania Ave., NW (6202 J)
Washington, DC 20460
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www.epa.gov/ghginfo/

Abatement of non-CO_2 GHGs: A Finnish perspective

Sami Tuhkanen
VTT Energy, Finland

Contents

- Finnish activities on the abatement of non-CO_2 gases
- GHG emissions in Finland
- Modelling work on non-CO_2 gases at VTT
- Abatement of emissions of HFCs, PFCs, and SF_6
  - key results of recent study made by Mr Sampo Soimakallio, Mr Teemu Oinonen, and Dr Riitta Pipatti
- Abatement of CH_4 emissions from waste management
- Conclusions

Some Finnish activities on the abatement of non-CO_2 gases

- Climtech technology programme
  - Abatement of HFCs, PFCs and SF_6
  - Abatement of CH_4 emissions from waste management (recycling, waste-to-energy, and landfill gas recovery)
- Finnish Global Change Research Programme (Figare)
  - Agrogas project: measurements of GHG emissions from agricultural soils and assessment of abatement measures
- Fortum and VTT
  - Measurements of CH_4 and N_2O emissions from fluidised bed combustion of peat and wood

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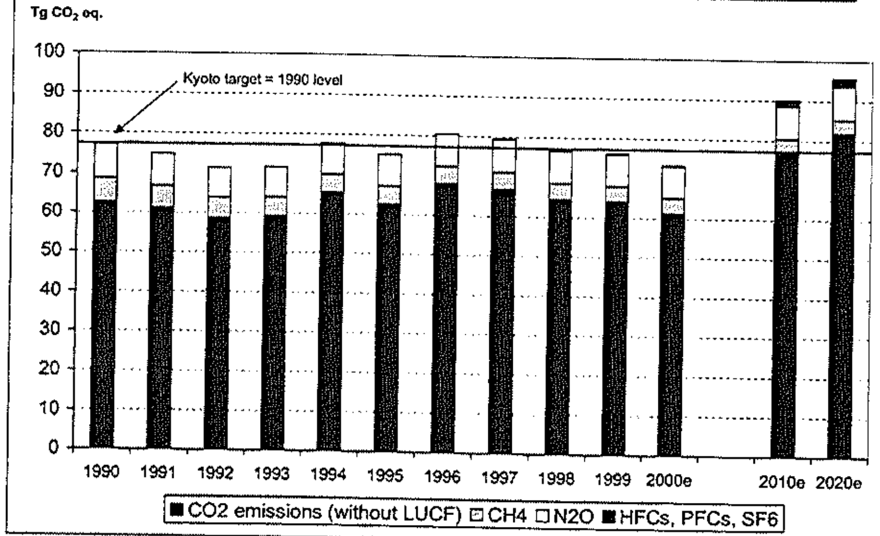
GHG emissions in 1990-2000 and the baseline estimate for 2010 and 2020

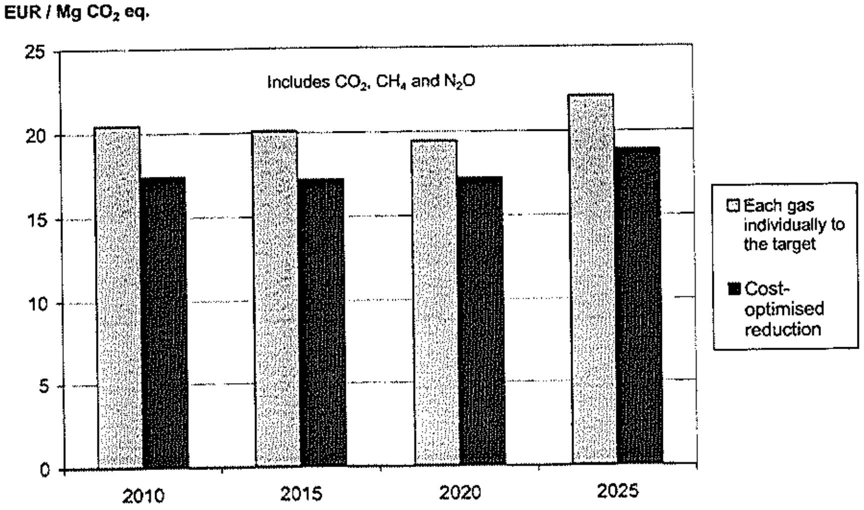


Non CO_2 gases in the energy system optimisation model (EFOM)

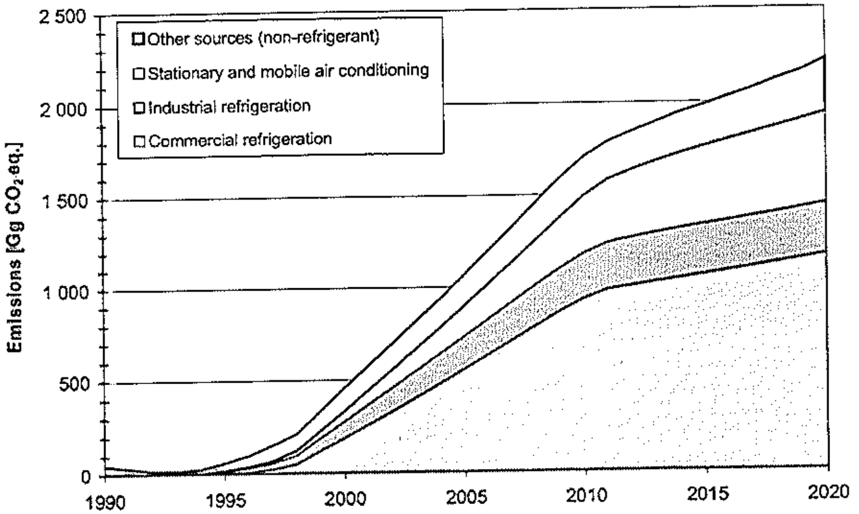
- Technology-related bottom-up model for supporting medium and long term policymaking
- Study periods up to 40-50 years
- Detailed description of the Finnish energy system
- Includes also comprehensive description of sources and abatement measures of CO_2, CH_4 and N_2O emissions in the energy system, industry, waste management, and agriculture
- Target function of optimisation: discounted total costs of the described system

- Future work: inclusion of HFCs, PFCs and SF_6

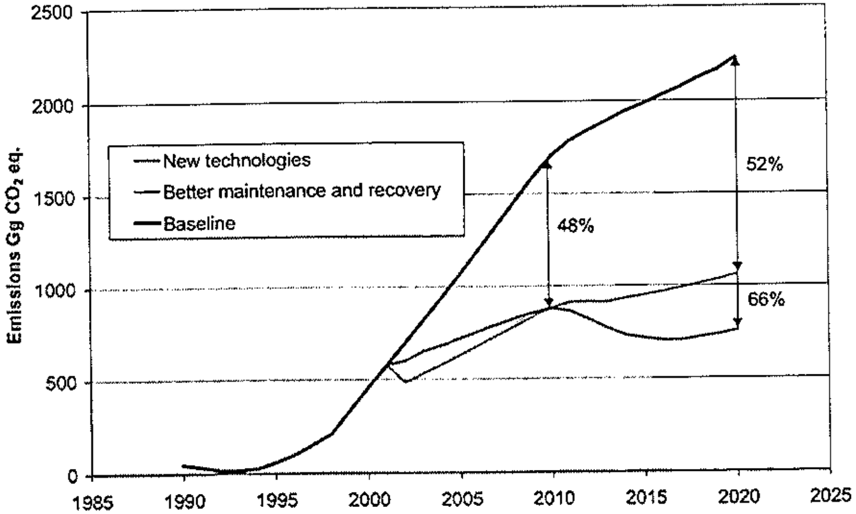
Average abatement costs in Finland



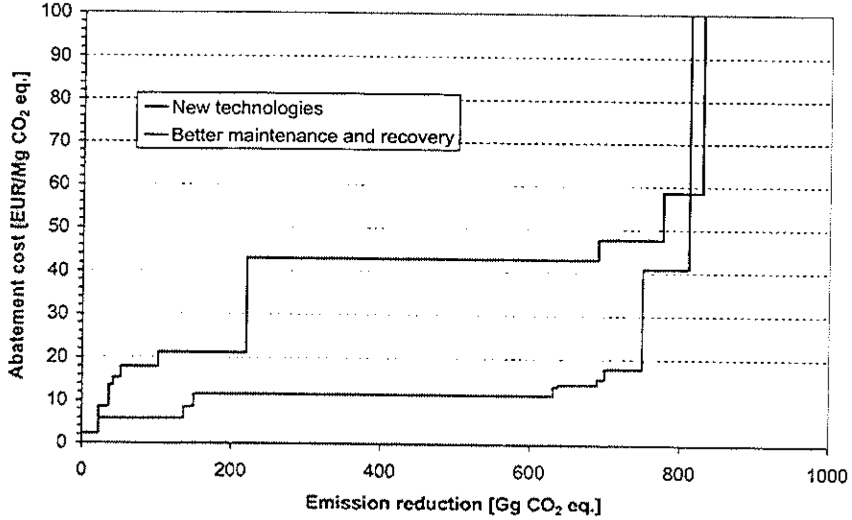
Baseline scenario for HCFs, PFCs and SF_6



Emissions of HFCs, PFCs and SF_6 in different scenarios



Abatement cost curves for HFCs, PFCs, and SF$_6$

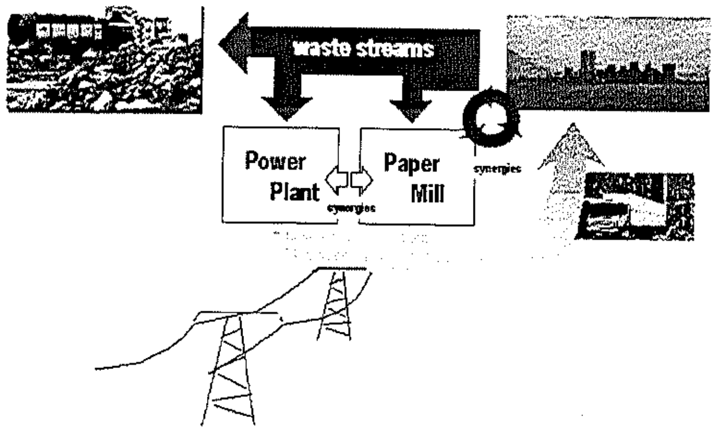


Waste management

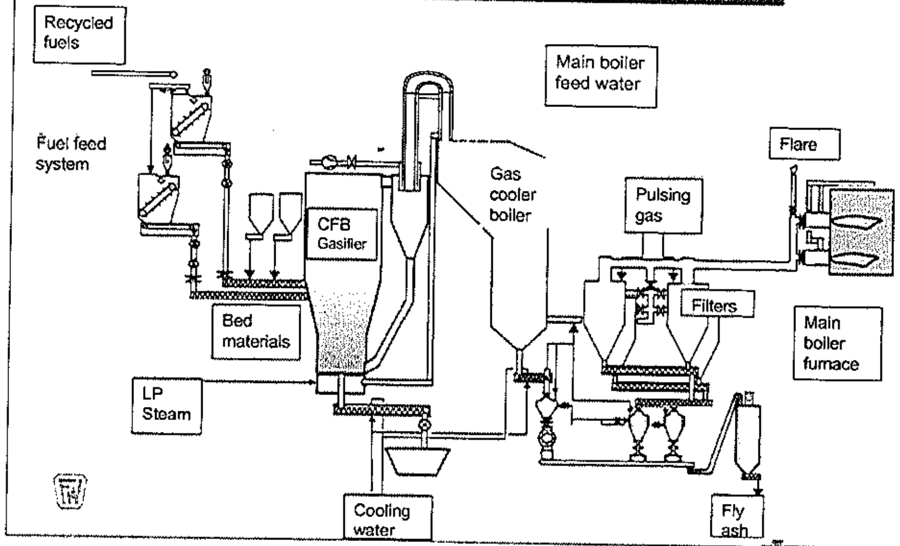
- Methane emissions from landfills have decreased more than 50% from the 1990 level due to reduced disposal
- Significant cost-effective emission reduction potential
- Mitigation measures:
  - increased landfill gas recovery (current recovery rate about 10%)
  - increased paper fibre recovery (currently over 60%)
  - centralised composting of kitchen and garden waste (20-30 %)
  - effective energy use of refuse derived fuels (RDF)
- Technologies and concepts:
  - Urban mill
  - Gasification of RDF connected to existing boiler

More efficient paper fibre and energy recovery

Urban Mill: Principle



RDF Gasification plant connected to large coal-fired CHP boiler



Conclusions

- The contribution of non-CO2 gases to the total emissions is quite small in Finland but the effect on abatement costs is significant
- Integrated multi-gas optimisation model is very useful for estimating the cost-efficiency of different abatement measures
- HFC emissions are increasing very rapidly but there are many cost-effective abatement measures
- In waste management CH_4 emissions have decreased significantly after 1990 but cost-effective reduction potential still exists

RIVM,
National Institute of public health and the environment

A number of activities in the area of CO_2 and non-CO_2 Greenhouse gases

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Activities on non CO_2 GHGs (I)

- EDGAR database on numerous emissions, the new version V3.0 will be ready soon,
  - www.rivm.nl/ieweb/ieweb/index.html
  - www.rivm.nl/env/int/coredata/edgar/
- IMAGE-model, is an integrated assessment model. CD-Rom with new version IMAGE 2.2 will be finalised soon. Called: 'IMAGE 2.2 implementation of the SRES Scenarios', www.rivm.nl/image/
- FAIR, Framework to Asses International Regimes for differentiation of commitments, downloadable interactive computer model, www.rivm.nl/fair/
- Scenarios, www.rivm.nl/ieweb/ieweb/scenarios/sres.html
- AirClim project, GHGs combined with other non GHGs i.e. gases causing acidification (SO2, NOx), including MACs

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Activities on non CO_2 GHGs (II)

- GECS project, Greenhouse gas Emission Control Strategies project, www.upmf-grenoble.fr/iepe/GECS/index.html
- European Topic Centre on Air and Climate Change (ETC-ACC) partners, RIVM, leads this EEA institution
- close connection with CPB, with WorldScan model, collaboration on CO_2 and non CO_2 costcurves (soon to be developed) ---> together with FAIR
- Generation of MAC curves with the TIMER-energy model, www.rivm.nl/ieweb/ieweb/tools/timer.html
- Work on uncertainties / uncertainty assessment
- Coming the 3th International Symposium on Non- CO_2 GHGs, in Maastricht, The Netherlands, 21-23 January 2002, www.vvm.to, www.vvm.to/ncgg-3.htm

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Further information

- www.rivm.nl
- www.rivm.nl/ieweb