Technologies for Reducing Non-Energy-Related Emissions

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Technologies for Reducing Non-Energy-Related Emissions

1. Introduction

In the long-term there are three main sources of reduced non-energy emissions, and these relate to the industrial processes sector, the waste sector, and the agriculture sector. Table 1 indicates the size of these emissions so far as the advanced economies are concerned.

Table 1: Non-Energy GHG Emissions in the Advanced Economies, 1990 to 2010 ($MtCO_2$–e)

Source	1990	2000	2010
Industrial processes	299	326	732
Waste	538	526	534
Agriculture	1457	1396	1486
Total of the above	2294	2248	2752
Land use change and forestry	-1389	-1171	-1071
Total non-energy	905	1077	1681

Sources: US EPA (2001) and CSES (2004).

Among the sources of non-energy GHG emissions from the *advanced economies*, agriculture is the largest, followed by waste and industrial processes.[1] Gross non-energy emissions are estimated to be 15.4% of all GHG emissions from the advanced economies in 2010. The relative importance of gross non-energy emissions in total GHG emissions is tending to decline because of the slow growth in emissions from waste and agriculture.

Net non-energy emissions from the advanced economies are reduced because of the considerable expansion in the carbon sink provided by forestry. The expansion of forestry has been cutting net non-energy emissions to less than half of gross emissions. Net non-energy emissions in the advanced economies are likely to be 10% of total GHG emissions by 2010, but this proportion is increasing because the rate of forestry growth is lessening, reducing the absolute level of carbon absorption.

Scheehle (2002) provides some information about non-energy emissions from the *developing economies*. Emissions from industrial sources were 225 Mt CO_2-e in 2000. Emissions from waste totalled 803 Mt CO_2-e in the same year. They are increasing by more than 2% per annum. They are already larger than waste emissions from the advanced economies and because there has been little take-up of advanced low-emission waste technologies used in the advanced economies, this divergence in trends is expected to continue for some time.

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[1] Detailed information on the nature of the activities that give rise to non-energy emissions are contained in CSES (2004).

Emissions from agriculture were 4028 Mt CO_2-e in 2000, almost three times the level in the advanced economies. Agricultural emissions in the developing countries are increasing by 1.6% per annum, well in excess of the rate of change in the advanced economies. Rice cultivation contributed 629 Mt CO_2-e to GHG emissions in 2000, agricultural soils 1944 Mt CO_2-e, and enteric fermentation 1235 Mt CO_2-e.

Gross non-energy emissions at 5056 Mt CO_2-e were more than double that in the advanced economies (2248 Mt CO_2-e) and they amounted to 33.9% of total GHG emissions compared with 15.4% in the advanced economies.

Estimates of the contribution of land use change and forestry to GHG emissions in the developing economies were not available. It is likely that both land clearing and forestry would make a positive contribution to GHG emissions so far as the developing countries were concerned. Overall, non-energy emissions appear to be a major contributor to overall GHG emissions from the developing countries.

2. Industrial Processes

Introduction

The rapid current and immediate future growth identified in US EPA (2001) is based on:

- the substitution of HFCs for CFCs in such areas as refrigerants, and aerosols and inhalers;
- the use of SF_6 as an inert gas in semiconductor production; and
- the use of SF_6 in magnesium foundries.

Other aspects of industrial process emissions are fairly stable in the advanced economies. This includes emissions from:

- cement production;
- chemical industry; and
- metals industries (immediate prospects of savings in declining use of coking coal in iron and steel production and the reduced use of carbon-intensive anodes in aluminium smelting).

Technologies

The general sources of emissions saving that are likely to occur across industry in an Optimistic Scenario relates to continuous improvements in process technology and technological progress relating to equipment maintenance and repair. Non-energy emissions from industrial processes occur as a by-product of chemical processes in industry. Incremental improvements in process technology relating to improved monitoring and control of processes lead to higher product yields from processes and hence lower emissions per unit of output. Leakages of emissions associated with equipment use can be reduced through improved maintenance and repair of equipment. Technological progress impacting on the efficiency of maintenance and repair will be based on sensors and controls that continuously monitor the functioning of equipment and thereby facilitate the use of pro-active maintenance strategies and self-repair technologies.

The major areas for specific emissions-saving technologies with respect to industrial processes, in order of their quantitative importance, are halocarbon production and consumption (along with SF_6 consumption), processes in the metals industry, and mineral products.

Emissions associated with halocarbon production and consumption could be expected to grow along with the use of certain equipment and technologies, particularly refrigeration and air-conditioning equipment. In addition, the manufacture of rapidly growing semiconductors and electrical equipment make use of SF_6. The substitution of other materials for halocarbons and SF_6 could make an important contribution to emissions-savings. Environmental concerns over the use of harmful refrigerant liquids have prompted the IEA Heat Pump Programme to examine this issue, in particular in relation to carbon dioxide. The main objective of the study on CO_2 as a working fluid in compression systems Annex 27) was to address the technical, safety and environmental matters associated with the use of CO_2 (IEA 2005). The studies show that CO_2 is a very promising refrigerant candidate as a replacement for SF_6.

In the metals industries the key areas of technological change that would save non-energy emissions are increases in the efficiency of recycling steel and aluminium, improvements in the competitiveness of electric arc furnaces for the manufacture of steel, and the use of inert anodes in aluminium smelting.

For mineral products, the main specific technological change that will impact on emissions in the long term would be the greater use of ground granulated blast furnace slag and fly ash as raw meal in cement production.

In the very long term, new technologies could be successful in reducing the non-energy emissions from industrial processes. It is unlikely that these emissions can be eliminated – ZET for non-energy processes does not appear to be possible.

Policy Implications

There are three areas of policy that need to be considered in relation to non-energy industrial processes.

Firstly, the framework for economic instruments needs to be broadened to take account of non-CO_2 emissions. For example, emissions trading needs to embrace the full range of greenhouse gases. Carbon taxes need to be adapted to include other greenhouse gases.

Secondly, regulation has an important role as an interim measure to encourage the diffusion of technology and innovation. For example, regulations could target reductions in the use of halocarbons and SF_6 in industrial processes, as indicated below.

Thirdly, the diffusion of technology could be facilitated through the use of benchmarking analysis for industrial processes.

The one specific area of industrial processes that will be heavily influenced by policy specifically addressed to non-energy emissions is the production and consumption of halocarbons. Trends in this area in the recent past have been greatly affected by the Montreal Protocol which sought to reduce consumption of ozone depleting substances such as chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs). The Montreal Protocol industries (air conditioning, refrigeration, foams, fire protection, aerosols and solvents) are, as a consequence of policies to reduce ozone-depleting substances, increasing their use of halocarbons (hydroflurocarbons or HFCs). The advanced economies are now developing regulations that will restrict the use of halocarbons across the broad range of their use. Similarly, it is assumed that regulatory intervention will limit the use of SF_6 with respect to the manufacture of electrical equipment and semiconductors.

3. Waste

Introduction

Between 1990 and 2000, it is estimated that the overall quantity of waste in the advanced economies increased by 2.5% per annum, in line with the rate of economic growth. However, GHG emissions from waste actually declined by around 0.3% per annum over this period. The savings in emissions were attributable to:

- the greater use of managed sites in solid waste disposal on land;[2]
- the composting of moist organic waste as opposed to landfill disposal;
- increased use of waste incineration as opposed to landfill in solid waste disposal (incineration occurring with energy recovery is very efficient compared with landfill sites);
- the capture of methane for commercial use (mainly electricity generation) from landfill sites;
- greater recourse to recycling as a means of dealing with potential waste; and
- improved technologies in the treatment of wastewater (CSES 2004).

GHG emissions from waste in the developing economies increased by 2.1% per annum. Stronger growth in the quantity of waste generated and a smaller take-up of emissions saving waste technologies contributed to this trend.

Technologies

Advanced technologies for the minimisation of GHG emissions from waste embrace three areas:

[2] Managed landfill sites are capable of greater efficiency in handling wastes.

- the minimisation of waste;
- the diversion of solid waste away from landfills; and
- efficiency improvements in waste management technologies used in landfills and wastewater treatment.

The minimisation of waste can be encouraged by recycling technologies that reuse materials that would otherwise go to waste. Advanced technologies incorporate recycling and reuse into original product and process design. Practicable means of giving effect to such principles include:

- designing lighter packaging and/or opting for more easily recyclable materials in packaging;
- reducing the variety of plastics used in durable manufactures;
- avoiding painting and putting labels on recyclable parts;
- using a modular architecture for durable goods to make them easier both to upgrade and to disassemble at end-of-life; and
- minimising or eliminating embedded metal threads in plastics.

The diversion of solid waste away from landfills can be encouraged by improved technologies in the composting and mulching of food and garden waste and improved efficiencies in waste incineration including improvements in the use of waste for electricity generation and cogeneration of heat and electricity.

Efficiency improvements in solid waste disposal in landfills can reduce emissions, particularly through the capture and use of landfill gas. Improvements in wastewater handling and treatment that would reduce emissions are the capture of methane and improvements in aerobic treatment processes and the handling of sludge.

In the long run, advanced methodologies for dealing with waste could become a characteristic of the overall production system. The characteristics of such systems would be:

- the concept of integrated production systems incorporating waste recovery, and going beyond this to include waste recycling from final product use and reuse in production; and
- the use of process integration techniques to optimise processes with respect to the generation of waste, and then optimum means of recovering and reusing waste generated at the final stage of consumption.

The introduction of such systems could imply, in some cases, the elimination of waste as a source of emissions. However, waste will continue to contribute to GHG emissions in many parts of the economy. It is difficult to eliminate waste and adopt waste recycling in decentralised activities, and advanced waste disposal systems are difficult to justify where populations are small and scattered.

Policies

The environmental impacts of waste management have diminished over the past decade in the advanced economies as a result of: (i) extensive regulation, especially concerning landfills and standards for incinerator emissions, and particularly in Europe; and (ii) the development of highly efficient new technologies in waste management.

Governments in the advanced economies have introduced a number of policies aimed at reducing the environmental impacts connected with increasing waste generation. These include:

1. Increased waste management planning aimed at preventing and reducing waste generation through recovery.
2. The application of the principle of extended producer responsibility for certain products that pose end-of-life problems, e.g. packaging, electrical and electronic waste, used tyres, used oils, batteries and end-of-life vehicles.
3. The use of economic instruments to internalise the costs of waste management and the environmental impacts of waste.
4. Cooperation to ensure the better management of international movements of waste.
5. The reorganisation of local administrative structures to cut costs and ensure more efficient waste management.
6. Encouragement to the development of more ecological waste management methods.

However, problems still remain. Some of the main problems are:

- insufficient disposal capacity in some countries which encourage the export of waste to neighbouring countries with lower environmental standards;
- extensive non-compliance with emission regulations and standards leading to unauthorised dumps, and sites and facilities that do not meet the technical requirements; and
- prices for waste management that do not reflect environmental externalities and fail to provide a coherent basis for the use of different potential methods of waste management.

The main policy issues for the future are:

- the encouragement of upstream product change and innovation to optimise waste with respect to environmental outcomes;
- the provision of adequate incentives for upstream innovation and downstream waste management;
- the provision of better data on waste; and
- improving compliance with waste management policies.

The overall trend in waste generation over recent years has been characterised by:

- a dramatic increase in packaging use for non-durable goods (particularly foodstuffs); and
- a considerable weight reduction of durable goods which has been associated with an increasing product complexity, an increasing diversity of the embodied materials, and a decreasing potential for recycling due to the substitution of metal by plastics.

The challenge for non-durable goods is to lighten packaging and use more easily recyclable materials. This aim can be fulfilled through incremental change. For durable goods, given their complexity, complete product redesign might be a critical part of reaching waste reduction goals, and this would necessitate radical innovation.

The goal of waste policies is to modify the pattern of business-as-usual product change in order to position goods on less waste-intensive innovation trajectories. Taxes and charges are more likely to induce innovation than standards. The issue of adequate waste disposal capacity needs to be addressed in the development of pricing policies.

It is very difficult to obtain an accurate picture of the trends in different types of waste because of the lack of reliable, comparable data. The most detailed and reliable data concern municipal waste which is thought to represent only a small proportion (approximately 14%) of total waste generation. Better knowledge of the facts (quantities of waste produced, recycled, composted, incinerated with or without energy recovery, put in landfills, exported, imported, by type, by origin, treatment capacity, and treatment costs) is essential if more effective waste management policies are to be developed.

Finally, the issue of non-compliance with existing waste management policies needs to be addressed (OECD 2004).

4. Agriculture

Introduction

In the advanced economies GHG emissions were kept down in the 1990s by a temporary reduction in livestock numbers. The longer-term trend is for very slow growth in emissions. The main sources of emissions arose from the disturbance of agricultural soils, enteric fermentation from farm livestock, and manure management. Land use change and forestry acted as a sink for CO_2, largely as a result of the expansion of forestry areas. However, the growth of forestry areas appears to be easing, hence the level of the carbon sink provided is reducing.

In the developing economies, the absolute level of emissions from agriculture is roughly triple that of the advanced economies. This is attributable to the substantial contribution of rice cultivation to methane emissions, the larger acreage devoted to agricultural activities, and larger numbers of livestock. The trend is for agricultural emissions to increase at around 1.5% per annum, considerably faster than in the advanced economies. Land use change and forestry may well be a positive contributor to GHG emissions in the developing economies as extensive clearance of forestry areas is occurring (reducing the carbon sink) and the clearance of land results in emissions of methane.

Technologies

Enteric Fermentation

One of the biggest source of emissions in relation to agricultural production is enteric fermentation, and this poses the greatest challenge for technological development. Currently, there are four main policies for reducing emissions from enteric fermentation.

1. The development of a practical vaccine to inhibit production of methane by rumen organisms in sheep and cattle. The vaccine has a high potential to provide significant abatement for livestock emissions, and is the option most likely to deliver abatement within the next few years.
2. Some work has been carried out on the capacity of feed additives to reduce livestock methane emissions.
3. Grazing management tools may support action to reduce emissions from livestock (AGO 2002).

Caution needs to be exercised as to the potential for policies aimed at reducing enteric emissions. There has been a fundamental failure worldwide to adequately study the physical and chemical interactions which occur between the multitude of rumen organisms. The continued failure in the past decade to define this basic ecology has left the livestock industries ill-prepared to develop strategies to reduce rumen emissions (AGO 2001).

New Zealand may be leading the way in the development of policies to reduce emissions from enteric fermentation. Farmers in New Zealand are being asked to contribute $NZ8.4 million ($A7.3 million) a year to help reduce greenhouse effects caused by enteric fermentation of sheep and cattle. The tax is aimed at providing a source of funds for research into livestock emissions of methane and nitrous oxide, which account for more than half of the country’s greenhouse gases. On current livestock numbers of about 46 million sheep and 9 million cows, the levy will be about NZ9¢ a sheep and about NZ72¢ a cow each year (Reuters 2003).

Manure Management

The simplest abatement approach is to minimise the manure production and loss of nitrogen in urine. Manure can be minimised by ensuring the energy requirements of the animals are met from the highest digestibility feed available, fed only at levels required for the desired animal performance. This is easily done in pig and poultry industries and to some extent in dairies. For poultry and pigs, inclusion of enzymes in the diet to digest soluble non-starch polysaccharides is becoming an industry standard procedure. It enables increased utilisation of feed by the animal, reducing excretion of energy in the faeces (AGO 2001).

Aside from using dietary design to minimise emissions, manure storage and disposal also provide opportunities to reduce emissions. In the case of feedlots and dairies it is assumed that animal manure can be collected relatively easily. Manure can also be readily collected from poultry operations and piggeries. Much manure is currently used as a fertiliser, and replacing it with synthetic fertilisers is expected to reduce N_2O emissions substantially, so long as the manure was used for a purpose that did not allow the formation of large amounts of NO_x. An obvious application for this manure is energy production (Turton et al. 2002).[3]

Agricultural Soils

Emissions from soil disturbance can be reduced through a range of practices including reduced tillage, changes in rotations and cover crops, fertility management, erosion control and irrigation management. Precision farming techniques will enable crop inputs, including nitrogenous fertilisers, to be more accurately directed towards essential needs. More research is needed on emissions of nitrous oxide from agricultural soils.

Reducing Other Agricultural Emissions

Methane emissions from rice cultivation, an important source of GHG emissions in many developing economies, can be minimised by adopting advanced water and nitrogen management strategies that improve the trade-off between rice production yields and greenhouse gas emissions.

Biomass field burning, also widespread in the developing economies can be reduced by such methods as:

- adoption of green cane harvesting;
- strategic native pasture management and practices including stocking strategies;
- stubble mulching and conservation tillage practices in cropping industries;
- increased strategic management of woody weeds; and
- alternative use of crop residues (such as cane trash for mulch) (AGO 2002).

Forestry

Strategies for improving the productivity of the forestry industries would facilitate an expansion of this industry and an increase in the net greenhouse sink in the growing phase of new forest plantations. The strategy for improving productivity in forestry relies on technological change in four areas.

1. Genetic improvement in existing tree crops.
2. Research on the characteristics of non-commercial tree and woody shrub species with a view to assessing commercial possibilities.

[3] However, emissions of NO_x may be substantial and for this reason the fuel may be unsuitable for use in areas where air pollution may be a problem.

3. Increasing the efficiency of silvicultural practices with a view to increasing output in relation to primary natural resource inputs – pest/disease control, modelling forest growth and yield, improving the design and management of systems to increase water availability, improve planting layout to maximise natural resource management and greenhouse benefits (biodiversity, shelter belts, restoration of hydrological balance).
4. Increasing the efficiency of forest product processing – new wood processing systems and products.

Reducing Emissions from Land Use Change

Emissions from the clearing of land for agricultural purposes are a feature of many developing economies. Technology can play a role in reducing this source of emissions by improving productivity on existing land, thereby reducing the incentive to clear additional land, increasing the returns from uncleared land within agricultural properties (for example, through farm forestry), and developing tools to facilitate the effectiveness of land restoration programs.

Reducing Agricultural Energy Emissions

Energy use is another issue relevant to all production systems, and is a significant factor in a few agriculture sectors such as mushrooms and aquaculture. For wider agriculture, electricity and natural gas energy use are likely to be a relatively minor source of national emissions. However, greenhouse gas emissions from the use of fuel in farm machinery may be important for individual farm enterprises. Reductions in fuel use can also address broader sustainability issues; for example, reducing pump use through more efficient water use and distribution, or reducing the use of tractors through minimum till.

The key area for future action is to identify the energy efficiency options for farms, rural businesses and communities. The reduction of energy use in agricultural production through:

- the expanded use of precision farming;
- increasing the use of renewable energy on farms;
- introducing farm energy budgets;
- re-using agricultural waste especially for on-farm applications;
- accelerating the replacement of old machinery with newer more energy-efficient equipment; and
- enhancing the use of alternative fuels and the use of transport modes with low emissions per tonne-kilometre of freight.

Bio-energy projects can offer market diversification for landholders, displacement of greenhouse emissions from fossil fuel use, environmental benefits such as salinity mitigation, solutions to waste disposal problems, increased rural employment, production of valuable co-products such as resins, fertilisers and activated carbon, and the potential to export technologies and services. They have their greatest application in relation to woody crops.

Timelines for Changes in Agricultural Technologies

Near Term Technologies

The main examples of near-term agricultural technologies that are aimed at reducing GHG emissions are:

1. Vaccines to inhibit production of methane from enteric fermentation.
2. Advanced manure management technologies to reduce emissions.
3. Reducing emissions from soil disturbance by adopting current-sate-of-the art practices in cop cultivation.
4. Adopting advanced water and nitrogen management strategies in rice cultivation.
5. Replacing biomass field burning with more advanced farm practices.

Long Term Technologies

The key emissions-reducing agricultural technologies in the long term would focus on the two major sources of emissions.

1. A comprehensive strategy for reducing methane from enteric fermentation, based on major R&D programs.
2. The development of major R&D programs focussing on the reduction of nitrous oxide emissions from agricultural soils and applying the solutions to this problem.

Vision for the Future

Agricultural emissions are likely to be subject to the following trends.

1. The field burning of agricultural residues can be eliminated as superior methods of handling residues re now available. These emissions are of quite minor importance.
2. Minimal emissions through major technological improvements with respect to manure management systems in intensive livestock systems, and rice cultivation. These emissions are of secondary importance.
3. Emissions from the enteric fermentation of livestock may be moderated by new technologies but are unlikely to be eliminated. The same goes for emissions from the cultivation of agricultural soils. These are the two major sources of agricultural emissions.

The Technology System

The technology system in agriculture has a number of distinctive characteristics. These relate to diffusion, innovation, and research and development.

Public research and development is a more important driver of technological change in the agricultural sector than almost any other sector. This in part reflects the fact that agricultural producers are principally based on small family enterprises which do not have the scale to realistically engage in research. As a consequence, in the advanced economies research is undertaken by the public sector or in cooperative efforts involving agricultural organisations and the public sector.

Innovation is largely driven by public and cooperative research. Current innovation by the agricultural sector is being stimulated by the role of several *general purpose technologies.* These comprise the following technologies.

1. Biotechnology. Biotechnology is playing a major part in boosting agricultural productivity. In relation the global warming, biotechnology is being used to inform the selection of animals for genetic traits to increase feed conversion efficiency and reduce emissions from enteric fermentation, and to secure genetic improvements in forestry.

2. Microtechnology. Microtechnology is used to develop sensors for optimising input efficiency, monitoring the health of plants and animals, and providing data on waste streams. In relation to climate change matters, the technology could be used to reduce emissions from agricultural soils.

3. Synchrotrons. These are a tool for gene mapping, fabricating microtechnology and nanotechnology objects, analysing proteomics and metabolomic structures in plants, analysing soil structure, root architecture. Their main impact will be on farm productivity which provides an economic basis on which to devote resources for reducing greenhouse gas emissions.

4. Nanotechnology. Nanotechnology can be used in developing diagnostics for detection of pathogens, toxins and viruses, diagnosis of diseases in plants and animals. It can also be used in waste management – removing contaminants, improving biodegradation. Nanotechnology can be deployed so as to improve the trade-off between increased productivity and increased GHG emissions.

5. Information technology. An important aspect of information technology is the growth of software that facilitates the efficient development of precision farming and whole farm management, techniques which should improve the trade-off between farm production and GHG emissions.

The *diffusion* of advanced technologies through the farm sector is encouraged by networking activities among farmers. These can take the form of self-help groups, and the use of extension services. Diffusion can be constrained by impediments to exit rates. The least successful farmers, who are on the margin of survival, will tend to have low rates of adoption of new technology because the risks are high when survival is at stake, capabilities of using such technology may be low, and knowledge of the technologies may also be low. Exit rates are likely to be reduced by support measures for the agricultural sector, commonly employed in a significant number of leading economies.

The other characteristic of the technology system in agriculture is the way in which new forms of management need to be introduced as a necessary complementary innovation to the new technologies. *Whole farm management* is about the management of nutrients, integrated pest management, and the management of soil, land and water. These advanced methods are aimed at optimising the relationship between inputs of natural resources and production. In so doing, the environmental footprint of farming can be lightened and greenhouse gas emissions reduced.

Finally, in order to make best use of the new technologies becoming available, and implement state-of-the art whole farm management, complementary innovation is required in *human capital*. This is an area in which lags can be identified in many advanced economies as well as in developing economies.

Policies

Overview

Significant emissions reductions in agriculture will be dependent in large part on the implementation of policies that encourage sustainable development in the sector. An overall climate change strategy for agriculture in the broadest sense needs to embrace the following elements:

- the development of market instruments for cost-effective abatement of emissions;
- improving knowledge of the way GHG emissions arise from agriculture and disseminating information on emissions activity;
- conducting research and development into means of reducing GHG emissions associated with agricultural production.

Market Instruments for Cost-effective Abatement

Emissions trading could establish a market for emission reductions and could allow for maximum flexibility in private actions to contribute to cutting national emission levels. There is potential for low cost abatement activity in the agriculture sector and for the sector to earn income from carbon sequestration credits. The inclusion of agricultural emissions in an emissions trading system could reduce the costs for many countries of meeting the Kyoto Protocol targets, but will be influenced by the cost and practicality of accurately quantifying emissions. Where emissions are from diffuse sources, as is the case for agriculture, it could be technically impossible or prohibitively costly to accurately measure direct emissions. However, agriculture has the potential for a range of low cost abatement activities such as farm forestry, which could result in a flow of revenue and investment from carbon credits into the sector. If monitoring issues can be overcome, it may be possible to design an emissions trading system in ways that could be attractive to agricultural producers (AGO 2002).

Improving Information

Greenhouse emissions and abatement opportunities occur in complex, whole farm management systems that incorporate a range of biophysical and production interactions influenced by strong economic forces. Opportunities for effective greenhouse action need to be considered in this broader context. The difficulties posed by the diversity and complexity of agriculture may be overcome by focusing on biophysical processes common across production systems. Modelling of these processes will be important to enable greenhouse to be considered in management action and decision making, including for productivity and for sustainable natural resource management (AGO 2002).

Public Research and Development

The main areas for public research and development are:

1. Enteric fermentation – (scope for reducing methane emissions per animal by selective breeding; understanding the linkages between pastures, feed intake, and enteric emissions; improving the knowledge of basic rumen ecology).
2. Studying the determinants of nitrous oxide emissions from agricultural soils in the context of specific pastures and crops).
3. Research on determinants of rice yields and determinants of methane emissions.
4. Research on the characteristics of non-commercial tree and woody shrub species with a view to identifying commercial possibilities.
5. Research on siviculture.

5. Conclusions

The earlier analysis of technologies that might reduce GHG emissions from the energy sector indicated the possibility of zero-emission technologies, or minimal-emission technologies being employed in the key parts of the energy sector. These technologies would embrace:

- transport vehicles powered by fuel cells or electricity dominating transport movements;
- industrial processes that utilise zero-emissions electricity or coal and gas used with carbon capture and storage technologies;
- commercial and residential energy use using distributed energy systems based on renewable energy;
- electricity production based on some combination of renewable energy, nuclear energy, or coal/gas with carbon capture and storage technology;
- other energy transformation, such as hydrogen production, oil refining, and the transformation of gas and coal, would use some combination of zero-emission electricity or non-renewable energy sources with carbon capture and storage.

In the non-energy sector, there are prospects for zero-emission or minimal-emission industrial processes and waste technologies. However, the potential for emission reduction in agriculture is less clear than for other sectors. At this stage the possibility exists for some reductions in the emissions-intensity of agriculture since technological paths can be defined that would secure this goal in relation to each of the major sources of emissions – agricultural soil, enteric emissions, and manure management. But a movement toward minimal or zero-emission agricultural processes does not appear to be feasible.

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