OPTIONS REPORT

Reducing Greenhouse Gas Emissions from Canadian Agriculture

Agriculture and Agri-Food Climate Change Table

JANUARY 2000

Options Report: Reducing Greenhouse Gas Emissions from Canadian Agriculture

Executive summary

In response to the Kyoto Protocol, Canada's First Ministers asked their Environment and Energy Ministers to develop a comprehensive national strategy to reduce Canadian greenhouse gas (GHG) emissions. The Ministers created the National Climate Change Secretariat who established 16 *Issue Tables* to examine options for reducing Canada's GHG emissions. In their *Options Reports*, the Tables identified, analyzed and evaluated policy options for GHG reduction in their sectors. This document is the Options Report for the Agriculture and Agri-Food Table.

Approximately 9.5% of the Canadian GHG emissions are attributed to agricultural production activities using the national inventory system, not including the use of fossil fuels or the indirect GHG emissions from fertilizer production. Unlike other sectors, carbon dioxide emissions from fossil fuel use account for only a small fraction of agricultural GHG emissions. Emissions from agriculture are primarily nitrous oxide associated with fertilizer and animal manure use, and methane associated with cattle and livestock manure. Agricultural crops and forage remove carbon dioxide from the atmosphere and store it in plant material above the ground and in roots, which add organic carbon to the soil. This plant material can be used as a sink when stored for long periods of time or can be used in products that replace fossil fuel.

The complex biological nature of processes involved in producing the dominant GHGs in the agricultural sector makes emissions highly variable and sporadic. Given the variability in emissions there are still many knowledge gaps in the measurement and understanding of agricultural GHG emissions. The situation is further complicated with the prospect of climate change because climate change could affect these biological processes. Because of these deficiencies, much of the work of the Agriculture and Agri-Food Table involved the assembly and assessment of limited available knowledge. The non-energy nature of emissions required a separate model for the agricultural sector because most models are based on energy consumption in the general economy.

The extensive and systematic search for GHG-reducing technologies identified only a few that with certainty could significantly reduce GHG emissions from agriculture at a low cost. In most cases little was known about the effect of alternative technologies or about the economic costs of the technologies. It became abundantly clear that more research was required to evaluate these technologies and to discover other technologies that could be even more effective in reducing GHG emissions.

The technologies that showed some verifiable low-cost reduction in GHG emissions involved carbon sinks which are currently not part of the Kyoto Protocol. Increased zero tillage, reduced summer fallow, improved grazing strategies, and conversion of cropland to wetland and wildlife habitats showed promise for net emission reduction as soil sinks. Agro-forestry and shelterbelts showed promise as forest sinks. Strawboard and other

fiber manufacture showed promise for net emission reduction as industrial sinks. If Canada is committed to GHG reduction regardless of Kyoto acceptance, these technologies are well enough known to be promoted actively. However, further investments in research and development are needed to develop and to scale up internationally acceptable measurement and verification systems to the national level.

Other areas showed promise to reduce GHG emissions including crop nutrient management, livestock nutrient management, manure management and biofuels. While some aspects of the technologies are documented, in each of these areas there was uncertainty about the effects of specific technologies or more important, the best technologies to employ. This uncertainty suggests more basic and applied research is required before specific technologies are promoted.

The research directed toward GHG reduction in agriculture is still in a very preliminary phase—this is a brand new problem. Not enough is known about the effects of the many technologies that are in use today. The technologies must be studied as part of farming systems, which are part of larger systems. This study will lead to a better understanding of processes and will allow the refinement of the best current technologies toward even more efficient technologies in the future. There are also outstanding issues about the best private and public institutions to achieve cost effective GHG reduction, and hence a need for continued policy development.

Despite significant knowledge gaps, the Table concluded that agriculture has a large potential to reduce net GHG emissions. The agricultural sector has adopted technologies that have reduced GHG emissions for other environmental and economic reasons. If the agricultural sector has the incentive to reduce net GHG emissions, history would suggest that the sector will respond, find and adopt technologies that further reduce net GHG emissions. There is potential for these gains to come from the use of better technologies to reduce direct GHG emissions and to increase the quantity of carbon sinks in soils, forests and agro-industrial products such as strawboard.

To reduce GHG emissions cost effectively, the Table recognized that policies cannot require monitoring and verification of individual actions, nor can they involve large increases in the cost of production. The sheer number of farmers and the complexity of the systems make the monitoring and verification of individual actions very difficult and expensive. In general, Canadian agriculture operates in global markets with very narrow margins and with little ability to pass additional costs on to consumers.

Given these limitations, our Table concluded that the most viable means of achieving reduction in agricultural net GHG emissions is to create and to promote technologies that increase profitability and that can be voluntarily adopted. While some technologies that increase profits and reduce GHG emissions do exist, part of the adoption strategy must be to discover and to develop new cost-effective GHG-reducing technologies. This research and development strategy must recognize the various development stages in the process and the appropriate role for the private and public sectors. Some of the already proven low-cost technologies should proceed through extension and incentive programs while more further research is undertaken to estimate more precisely their GHG impacts.

The recommendations contained in this report suggest how government can create an environment to foster net GHG reduction in the agricultural sector at a minimal economic cost to the sector and to the Canadian economy as a whole. These recommendations are supported in the body of the report with a description of the analytic approach of the Table and the scientific and economic rationale the Table used to develop them.

GHG emission reduction will require both government and industry action. Some research and development resources provided by the government can create the potential for the industry to benefit from adopting better technologies. An informed industry will also recognize that given the importance of the environment in international markets, and the potential to trade emission reductions, developing an industry with low GHG emissions may be good business. Finally, the government should reiterate its commitment to the reduction targets and infer that any sector that does not find ways to contribute to GHG reduction could face compulsory measures at some point in the future.

The recommendations that follow represent the output from a 16-month process of research and deliberation by the Table. They provide a framework for the national strategy for the cost-effective reduction of net GHG emissions from agriculture. The human and social capital base embodied in this Table is a considerable resource that could be consulted in the further refinement and operation of the GHG strategies.

Many of the recommendations must be initiated immediately and simultaneously to have a real impact by the 2008–2012 commitment period. Research takes time. The sooner research commences the sooner results will be produced. The same timing issue exists with extension programs—the process of adoption takes time. This timing is especially critical for those individuals in those parts of the agricultural sectors that are expanding and investing in the technology that they will use in 2008. The early action items encourage the technologies which are clearly cost-effective and should be pursued as soon as possible. The urgency to commence work on many fronts suggests the need for an immediate commitment of resources and the need for an immediate and concerted effort to create the institutions and policies to allocate these resources. This would require significant consultation with the primary stakeholders.

The Table offers eleven recommendations:

Recommendation 1. Governments should provide resources to assist the extension of knowledge required to foster the adoption of proven technologies. For example, governments should work with the industry to encourage the adoption of improved grazing management systems, feeding strategies, and zero tillage cropping systems.

Recommendation 2. In recognition of the public benefits where cost-effective technologies are well known, and an economic incentive is required for their adoption, governments should provide public incentives for the adoption of GHG-reducing technologies. These public incentives would stay in place until markets for emission reductions in the agricultural sector are established. For example, governments should work with the industry to develop financial incentives for the planting of shelterbelts.

Recommendation 3. The federal government should continue to insist on the inclusion of soil, forestry and industrial sinks in the international protocol and to ensure that the guidelines of the Intergovernmental Panel on Climate Change (IPCC) reflect Canadian conditions.

Recommendation 4. Governments should create research funds managed by the agricultural sector to assist in research and development of applied technologies for GHG reduction.

Recommendation 5. Governments should provide public resources to support basic research activities for net GHG reduction particularly in the areas of crop nutrient management, livestock nutrient management, manure management, carbon sequestration, and biofuels.

Recommendation 6. As part of a national strategy, governments should work with the agricultural sector to refine national inventory, measurement and verification systems for net GHG emissions and to reflect improvements in technology. Monitoring should include the collection of more accurate raw data and the refinement of analytical models that can be used to manage and to assess the effectiveness of GHG-reduction policies.

Recommendation 7. As part of the national process, where possible, GHG emission trends in all sectors of agriculture in all provinces should be monitored and published.

Recommendation 8. Governments should work with the agricultural sector to develop targets for the reduction of GHG emissions along with incentives for meeting the targets.

Recommendation 9. Governments should assist the agricultural sector in the development and refinement of best management practices for the reduction of GHG emissions.

Recommendation 10. Governments should provide resources to assist policy research, market research, legal research and other public infrastructure to facilitate the development of trading mechanisms that reward reductions in net agricultural GHG emissions.

Recommendation 11. Governments should co-operate with private sector partners to develop a strategy that will enhance the agricultural sector’s ability to adapt to climate change using sustainable farming systems.

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List of acronyms, initializations and abbreviations

AAFC	Agriculture and Agri-Food Canada
CEEMA	Canadian Economic and Emissions Model
CRAM	Canadian Regional Agricultural Model
GHG	Greenhouse gas
GHGEM	Greenhouse Gas Emissions Model
IPCC	Intergovernmental Panel on Climate Change
PAMI	Prairie Agricultural Machinery Institute
PFRA	Prairie Farm Rehabilitation Administration
WTO	World Trade Organization

CH_4	methane
CO_2	carbon dioxide
N_2O	nitrous oxide

1 Introduction

1.1 The global problem of greenhouse gas emissions and the national policy process

Greenhouse gases (GHGs) act to trap long-wave radiation emitted from the earth's surface, increasing the warming of the atmosphere and influencing climate patterns. The major GHGs are carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). Human activity has increased emissions of these GHGs into the atmosphere. As these GHGs accumulate, they could adversely affect the global climate. This problem gained international recognition when the United Nations Bruntland Commission published *Our Common Future* in 1987. It is in response to this threat that an international effort has been organized to reduce GHG emissions.

In 1992, Canada signed the international Framework Convention on Climate Change in Rio de Janeiro, where many countries agreed to stabilize GHG emissions. Despite the agreement, emissions continued to grow. In 1997, the parties to this earlier agreement met again in Kyoto and made further commitments to limit and reduce GHG emissions. In the Kyoto agreement, the developed countries of the world agreed to specific emission targets to be achieved during the 2008–2012 period, relative to a 1990 baseline year. Canada committed to a reduction in GHG emissions to a level 6% less than 1990 emissions.

In response to the Kyoto Protocol, Canada's First Ministers asked their Environment and Energy Ministers to develop a comprehensive national strategy to reduce Canadian GHG emissions. The Ministers created the National Climate Change Secretariat. The Secretariat established 16 *Issue Tables* to examine options for reducing GHG emissions. Members of the Issue Tables included representatives of federal and provincial governments, stakeholder groups and subject matter experts. The membership of the Agriculture and Agri-Food Table is presented in Appendix A.

The Issue Tables that dealt with specific sectors in the economy produced two reports: a *Foundation Paper* and an *Options Report*. In their *Foundation Papers*, the Tables identified the GHG emission sources and the opportunities for GHG reduction in their sectors. In their *Options Reports*, the Tables identified, analyzed and evaluated policy options for GHG reduction in their sectors. This document is the *Options Report* for the Agriculture and Agri-Food Table, hereafter referred to as "the Table."

The Options Reports presented by each Table will be compared and analyzed to develop a National Implementation Strategy. At a joint meeting in December 1999, the Environment and Energy Ministers will consider the National Implementation Strategy. The First Ministers will then consider their recommendations in 2000. For further information on the National Climate Change Process or the sectoral Tables, go to the National Secretariat web site (www.nccp.ca).

1.2 The agricultural sector and greenhouse gas emissions

Approximately 9.5% of the Canadian GHG emissions[1] are attributed to agricultural production activities, not including the use of fossil fuels or the indirect GHG emissions from fertilizer production. The sources of GHG emissions from the agricultural sector are very different from other sectors. For the agricultural sector, N_2O emissions associated primarily with agricultural nitrogen sources (fertilizer and animal manure) represent 61% of GHG emissions, CH_4 from ruminants and other sources represent another 38%, while net CO_2 emissions account for less than 1% of GHG emissions. In other sectors, CO_2 emissions associated with burning fossil fuels represent the majority of GHG impacts.

The complex biological nature of processes involved in producing the dominant GHGs in the agricultural sector make emissions highly variable and sporadic. N_2O, CH_4 and CO_2 are produced and consumed by the biological processes in agricultural ecosystems. The net GHG emissions are the difference between these competing processes. Several environmental factors such as water content, temperature, and nutrient supply, as well as agricultural management practices interact to influence both the production and consumption of each of these gases. For instance, a few days during the spring melt period may account for over 90% of the annual N_2O emissions in some ecosystems.

Large uncertainties exist in our estimates of CH_4 emissions from the agricultural sector because of the complex relationship between diet and CH_4 production in ruminants and the limited knowledge of CH_4 emissions from animal manure storage and wetlands. The variations in time and space of organic matter content within a field, make the precise measurement of net CO_2 emissions difficult. Given the variability in emissions, there are still many knowledge gaps in the measurement and understanding of agricultural GHG emissions. The situation is further complicated with the prospect of climate change. The agricultural sector must not only adopt measures that will reduce GHG emissions but also do so while adapting to climate change.

Despite significant knowledge gaps, the agricultural sector has a large potential to reduce net GHG emissions. The very foundation of the sector is the management of photosynthetic activity, which uses solar energy to convert water, nitrogen, other nutrients and atmospheric CO_2 into food and industrial products. As these products are digested and broken down by biological processes, much of the CO_2 and nutrients are returned to the environment as part of the cycle. The ability to manage these solar-powered nutrient cycles puts the agricultural and forestry sectors in the unique position to influence both the emission and sequestration of GHGs.

[1] In this report, the quantities of emissions are expressed in the CO_2 equivalents of the Intergovernmental Panel on Climate Change (IPCC). These equivalents consider the global warming potential of each gas. With this measure 1 tonne of N_2O is equivalent to 310 tonnes of CO_2, and 1 tonne of CH_4 is equivalent to 21 tonnes of CO_2.

The agricultural sector has been adopting technologies that reduce GHG emissions for environmental and economic reasons. This reduction has allowed the sector to grow significantly since 1990 while emissions have shown only modest growth. The sector has become more fuel efficient with the adoption of zero tillage. Also, zero tillage has the added benefits of reducing soil erosion and sequestering atmospheric carbon to increase the organic carbon content of the soil. In the livestock industry, feed efficiency and grazing management have improved steadily, helping to reduce the nitrogen content of the manure. Measures to control nitrate movement to groundwater and odor emissions have decreased GHG emissions from manure storage and application. Shelterbelts have been planted which sequester carbon from the atmosphere. These developments have reduced the net GHG emissions in the agricultural sector.

If the agricultural sector is encouraged to reduce net GHG emissions, history would suggest that the sector will respond, find and adopt technologies that further reduce net GHG emissions. As we outline in this report, there is potential for these gains to come from two sources: reduced direct emissions, and the increase in the quantity of carbon sequestered in soils, forests and agro-industrial products such as strawboard. The objective of this report is to outline options whereby the government can create such an environment. The recommendations put forward are supported by a description of the scientific and economic rationale that the Table used to develop these options.

1.3 Objective of the report

The report summarizes the activities and analyses of the Agriculture and Agri-Food Table. It presents options for reducing net agricultural GHG emissions as part of a national strategy for meeting the commitments made under the Kyoto Protocol. The options for the food processing sector are discussed in a separate document.

1.4 Outline of the report

Section 2 outlines the systematic process the Table used to identify the measures that had potential. Section 3 describes the eleven potential mitigation strategies selected for detailed study. Section 4 describes the economic modelling process and the interpretation of results of the economic analysis. Section 5 contains a discussion of the challenges and opportunities for the use of GHG mitigation policy measures in the agricultural sector. Section 6 summarizes the results of the Table’s search for actions to reduce GHG emissions. Section 7 concludes the report with how to implement the process and the Table’s recommendations.

2 The systematic search for actions to reduce greenhouse gases

2.1 The Table process

The Agriculture and Agri-Food Table first assembled at an organizational meeting on June 30, 1998 in Toronto. Since then the Table had 15 meetings at various locations (Appendix B). The Agriculture and Agri-Food Table represents the primary agricultural sector as well as the food processing sector. These two sectors have very different sources of emissions associated with their activities and the options for reducing these emissions are also different. For this reason the Table considered the two sectors separately. The food processing sector produced a separate Foundation Paper and Options Paper for its sector. This report focuses on the primary production side of the Agriculture and Agri-food Sector.

2.2 The analytical approach

One of the greatest challenges in formulating a GHG reduction strategy for Canadian agriculture is the state of knowledge of the magnitude and processes contributing to GHG emissions. Uncertainty surrounding ratification of the Kyoto Protocol, the inclusion of soil sinks[2], and the potential establishment of markets for emission reductions further complicated the analysis. Much of the early work of the Table therefore was directed at assessing the current state of the scientific knowledge and developing a general understanding of the nature and magnitude of GHG-producing processes in the agricultural sector. Time constraints, dictated by the larger national process, were a major factor influencing the nature and extent of the Table's activities. The time-line of the Agriculture and Agri-Food Table is outlined in Figure 1.

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[2] A sink is defined as any process, activity or mechanism which removes a greenhouse gas, an aerosol, or a precursor of a greenhouse gas from the atmosphere.

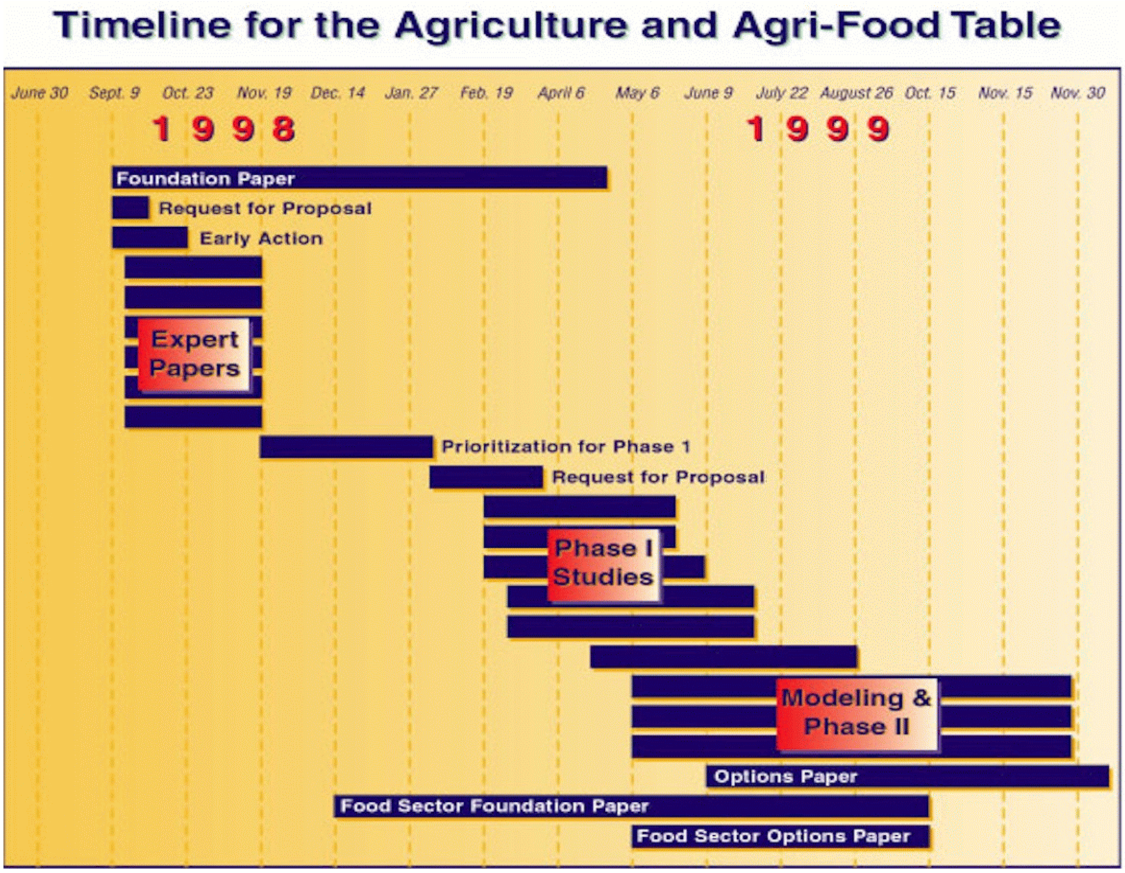

Figure 1: Time-line for the various phases and processes involved in the deliberations of the Agriculture and Agri-food Table

2.3 The Foundation Paper

The Foundation Paper was commissioned in September 1998 and is based on a draft version of "The Health of Our Air" (Janzen et al. 1999) The Table reviewed and revised the Foundation Paper and accepted and submitted the final draft in April 1999. The Foundation Paper is available in both English and French on the National Secretariat web site (www.nccp.ca).

2.4 Expert papers

In the compilation and review of the Foundation Paper, several areas of uncertainty were identified. At the September 9, 1998 meeting of the Table, the topic areas that required further study were identified and discussed. The Table then commissioned expert papers to address these areas. The results of these expert papers were presented at the workshop in Montreal on November 19–20, 1998. A list of the papers that were presented can be found in (Appendix C). The abstracts are posted on the Agriculture and Agri-Food Canada (AAFC) Environment Bureau web site (http://www.agr.ca/policy/environment/). A full version of the workshop papers (English only) are available from the Environment Bureau.

2.5 Phase I

At the meeting in Calgary on December 14, 1998, the Table identified the general areas that had the most potential as mitigation options. A Request for Proposal (RFP) was prepared for the following eight subject areas:

- grasslands and grazing management (CO_2, N_2O and CH_4)
- soil management (CO_2 and N_2O)
- soil nutrient management (N_2O)
- livestock feeding and management (CO_2, N_2O and CH_4)
- use of crop residue for industrial purposes (CO_2)
- carbon storage and water management (CO_2, N_2O and CH_4)
- manure management (CO_2, C_2O and CH_4)
- biofuel production (CO_2 and N_2O)

Carbon storage and water management involve two distinct subject areas; therefore two independent studies were requested. In addition, the Table consulted an earlier report prepared by the Prairie Farm Rehabilitation Administration (PFRA) which evaluated the potential carbon sequestration associated with farm shelterbelt plantings (PFRA 1998). The overview relative to agricultural systems involved in biofuel production was provided by one of the expert papers presented at the Montreal meeting (Coxworth and Hucq 1998) and a regional assessment for Southern Ontario (Levelton Engineering Ltd. 1999).

Phase I had two stages. In Stage I, the consultants were asked to provide a preliminary analysis of a long list of potential actions to reduce GHGs. The Table selected a subset of these actions that had the greatest potential for GHG reduction. In Stage II, the consultants were asked to provide a detailed examination of the selected actions. This analysis involved the consideration of policy measures that could be used to bring about each of the GHG-reducing actions in the agricultural sector.

The consultants were asked to provide estimates of GHG reduction potential, potential adoption rates, and economic/social impacts. The potential measures identified in Phase I, Stage I are listed in Appendix D. The data collected in Phase I, Stage II were used as input in Phase II.

2.6 Phase II

The Table considered that trade-offs exist between emission levels and economic indicators and that an understanding of these relationships would be important to all industry participants. The objectives of Phase II were to develop the analytical framework that could be used to estimate current and future GHG emissions from agricultural activities under "baseline" or business-as-usual (BAU) conditions and to use this same framework to assess the GHG mitigation actions recommended by the Table at the conclusion of Phase I deliberations. Funds were therefore directed toward the development of an agro-ecological economic modeling system that can simultaneously assess the economic and GHG emission impacts of agricultural practices at regional and national levels. Mitigation actions that appeared promising following this analysis were then subjected to cost curve analysis and assessed for economic, other environmental, social and health impacts, as well as any changes to sectoral and inter-sectoral competitiveness.

2.7 Links to other Tables

The Agriculture Table interacted with several other Issue Tables throughout the process. These interactions took place in a variety of ways and had varying degrees of success.

The greatest interaction was with the Sinks and Forestry Tables where common interests in the role of carbon sinks and their treatment in the international forum resulted in the formation of joint working groups. There were three common members on these Tables. Some agriculture staff attended meetings of all three Tables and shared the analysis of the Agriculture Table. Some members of the Sinks Table attended the Agriculture Table meetings. The Sinks and Forestry Tables produced independent Options Reports that contain information relevant to the deliberation of this Table. While the details presented in these reports may differ (e.g. estimation of the size of a particular sink), the general recommendations and recommended actions are complementary.

Many of the interactions simply involved a presentation to the Table (e.g. Transportation Table, see Appendix B). In some cases the products of other Table's deliberations were considered (Adaptation Table). For many of the Tables there was no apparent interaction.

The limited scope of the interactions during the Table’s process suggests a need for more consideration of some of these linkages. Transportation is a GHG issue for the agricultural sector and vice versa. Climate change and adaptation strategies are important for the agricultural sector. Public outreach is of common interest. Carbon trading mechanisms will have important direct and indirect impacts on the agricultural sector. Each of these linkages needs to be understood better and considered carefully in the complex process of developing a national strategy.

2.8 Development of the recommendations

The recommendations of the Table were developed after several months of deliberation. It was a complex task, made far more difficult by gaps in the knowledge about the GHG effects and the costs of specific technologies. The process began with the consideration of the technical information leading to the drafting of a general strategy to deal with the broad issues. This general strategy was followed by the drafting of specific recommendations, which were considered and revised to yield the final set of eleven presented in this report.

3 Overview of Phase I

3.1 Grasslands and grazing management (CO_2, N_2O and CH_4)

Grasslands represent 26.3 million hectares or one third of Canada's agricultural land base. The majority of our grasslands are managed to provide pasture or to conserve forage for the Canadian cattle and horse herds, with minor allocations to sheep and other small ruminants, bison, elk, and the growing export market of forage.

Grasslands are an important carbon and methane sink. The majority of soils classified as grasslands in Canada have higher levels of soil organic carbon than similar soils under cultivation. Mitigation strategies for grasslands focus on small to moderate improvements in soil carbon levels, primarily through the prevention of overgrazing which leads to dramatic changes in plant species, potential desertification (reverting to a desert), and decreased plant growth.

Improved management of grasslands is expected to result in small increases of CO_2-C sequestered per unit of land which, given the large land base, could result in a significant contribution to an improved GHG balance. The main sources of GHGs are N_2O released during the biological process of denitrification and CH_4 released from enteric fermentation by ruminants, most specifically cattle, grazing the forage produced on these grasslands. Many of the mitigation strategies considered have the potential to increase soil carbon sequestration, but could result in increased N_2O and CH_4 emissions due to improved soil fertility and increased cattle numbers on the land.

The technology to implement the proposed mitigation strategies for grasslands is currently available. However, the adoption rate is low due to initial investment costs for fencing and watering systems, and the need to upgrade the pasture and animal management skills of producers. The identified mitigation strategies are not expected to affect adversely the competitiveness of the Canadian beef cattle sector. They are in line with current programs directed toward the maintenance or improvement of habitat and water quality.

3.2 Soil management (CO_2 and N_2O)

Cultivated agricultural lands represent two thirds of Canada's agricultural land base. Soil carbon sequestration on cultivated lands is dependant on three key factors: land tillage practices, plant species selected, and soil nutrient and water inputs. Minimum and zero tillage practices initially received attention from researchers and producers as an important tool in reducing soil erosion, improving water conservation, and reducing farm machinery, fuel and labour costs. More recently, the benefits of reduced tillage are being recognized relative to increased soil carbon sequestration.

The effect on N_2O emissions however, is less clear. The contrasting information about tillage practices on N_2O emissions resulting from Canadian based research appears to be related directly to a poor understanding of the biological processes associated with N_2O production and to the limited technology available to measure the emissions accurately.

Based on current adoption trends, the CENTURY model predicts that agricultural soils will shift from being a net producer of CO_2 to a net sink by 2000. The rate of adoption, without intervention, of minimum and zero tillage practices is expected to be greatest in the Canadian Prairies due to the benefits related to soil erosion and water conservation. There is less interest in some areas of Canada where zero tillage has been associated with the delayed warming of soils and shorter growing seasons.

The practice of leaving cropland idle or in "fallow" for a year was an important management tool in the more arid regions of the Prairies for water conservation and pest control. Improved technologies such as zero tillage, a better understanding of soil quality and a wider option of crops are already resulting in a trend toward reduced acreage in summer fallow. There is a consensus among researchers that a reduction in summer fallow acreage will reduce N_2O emissions and increase soil carbon sequestration but uncertainty of the measurement has hindered exact estimates.

Crop rotations, plant species selected and residue management are recognized to have potential implications in soil carbon sequestration and N_2O emissions. However, specific information regarding mitigation potential is more limited than for the other soil management strategies discussed.

The geographic and climatic diversity of Canada's agricultural land requires that policies promoting change in land management practices be considered at a regional level and be sensitive to the increased production risk related to unpredictable weather. Best management practices that have been identified for reduced soil erosion, reduced nutrient leaching, water conservation and improved water quality will compliment the goal to reduce GHG emissions from arable agricultural lands.

3.3 Soil nutrient management (N_2O)

Current estimates suggest that nitrous oxide (N_2O) accounts for over one-half of agricultural GHG emissions, the majority originating from denitrification processes in the soil. Land management strategies directed toward the incorporation of atmospheric CO_2-C into soil organic matter must be evaluated relative to the impacts on N_2O emissions because the soil carbon and nitrogen cycles are linked, and because N_2O is a highly potent GHG. N_2O can be produced throughout the soil during nitrification and denitrification processes, with production at the deeper levels being absorbed or diffused downward. The portion of N_2O that is produced near the soil surface or that is not able to diffuse downward due to an inhibiting layer, for example a frozen ground layer in the spring, will result as a flux into the atmosphere. The focus of GHG mitigation strategies relative to soil nutrient management is to reduce this soil N_2O flux into the atmosphere. Farm nutrient management plans are already being introduced as a mechanism for optimizing nitrogen applications in various regions across Canada and could be a suitable strategy for reducing N_2O emissions.

The conditions that govern N_2O production and emission from agricultural soils are complex and poorly understood. A key difficulty is our inability to quantify N_2O emissions due to the extreme variability in time and location of the emissions. Seasonal distributions of N_2O emissions have been well characterized; however, our ability to measure or predict actual amounts of N_2O emissions from a particular site at a particular time is far from satisfactory. Factors such as rainfall/snowmelt, temperature, freezing/thawing and management practices such as fertilizer application, manure application and tillage, influence nitrification and denitrification processes, the time lag between production and emission of soil N_2O, and the relationship between production and emission rates of N_2O.

Several models, including the DNDC (DeNitrification DeComposition), CENTURY, Expert-N, and ECOSYS models have been developed to attempt to describe nitrogen dynamics in Canadian soils at various scales. Rigorous testing and validation are still required before these models can be used with confidence in efforts to assess GHG mitigation strategies.

Mitigation strategies and technologies considered by the Table focus on improved efficiency of nitrogen use by various crops. Some of these strategies and technologies are currently being considered by producers as measures to reduce crop input costs while others have increased input costs with little definitive data on the magnitude of GHG reductions. Policies must proceed cautiously, with a major effort directed toward research to improve our ability to measure and to model N_2O fluxes on a regional basis and for specific cropping systems.

3.4 Livestock feeding and management (CO_2, N_2O and CH_4)

Canada's 1996 Greenhouse Gas Emission Summary reports that 42% of direct emissions from the agricultural sector are associated with livestock production. Digestive processes involving the breakdown of plant materials under conditions that are oxygen-free or oxygen-limited result in CH_4 production, accounting for 28% of agricultural emissions. These conditions are found in the large intestines of all animals and in the fore-stomach or rumen of ruminant animals which include cattle, sheep, goats, bison, elk and deer. CH_4 is produced by all animals with an estimated 97% of enteric emissions associated with beef and dairy cattle. Indirect emissions from livestock operations, totaling 14% of agricultural emissions, are associated with the handling, storage and land application of manure. Microbial decomposition of manure can result in CO_2, CH_4 and N_2O emissions; the relative portions being dependent on factors such as manure dry matter, carbon and nitrogen content, as well as temperature and oxygen availability during storage.

Livestock production can be equated to "value-added" production because it involves the feeding of lower quality feed to animals for the purpose of producing high quality, high value food or fiber end products. Since CH_4 and N_2O losses from livestock production can be directly equated with energy and protein losses, GHG mitigation strategies adopted by livestock producers will result in direct improvements in production efficiencies. Conversely, any feeding and management strategies adopted for the purpose of reducing feed costs per unit of an animal product sold will have a positive effect on GHG mitigation. In many cases, GHG mitigation strategies will positively impact social and environmental concerns such as odor control and water quality. Other social issues, in particular housing and management changes to satisfy animal welfare, may have a reverse effect on GHG mitigation.

The livestock industry in Canada has undergone dramatic changes since 1990. The industry has reduced farm numbers, increased production unit size, increased production efficiencies, and had regional shifts in livestock numbers. The overall improvement in efficiency that has accompanied these changes may have reduced GHG emissions in the agricultural sector since 1990. More importantly these changes could affect the sector's ability to respond to GHG policies.

Livestock production, unlike crop production, has the opportunity for major expansion within Canada because current production levels are well below resource constraints and world demand for the products is high. Mitigation strategies must be sensitive to the need to maintain competitiveness if they are to be readily adopted by the agricultural sector. Immediate efforts should focus on three areas:

- industry awareness of the issue
- establishment of a database that accurately assesses current GHG emissions on the basis of livestock management system and region
- incentives to bring existing technologies that improve feed utilization to commercial readiness (CH_4 inhibitors for ruminants, diet formulation on the basis of amino acids, sperm sexing)

Long term efforts should focus on three different areas:

- new technology development (biotechnology) to cause major changes in digestive processes to improve nutrient utilization
- continued efforts to improve the reproductive and genetic potential of the animal
- increased emphasis on plant breeding/genetic engineering of plants to improve nutrient profiles and utilization for animal feed

3.5 Use of crop residue for industrial purposes (CO_2)

Current wording in the Kyoto Protocol does not give credit to the processing of crop residues resulting in the long term storage of carbon in industrial products. This wording is under discussion, and on that basis, it was considered useful to explore the carbon sequestration potential of using crop residues for industrial products.

Crop production requires that plants take in large amounts of CO_2 through the process of photosynthesis and then produce carbon. Some of this carbon-containing plant material is removed at the time of harvest. The remaining plant parts such as straw, chaff and roots must be incorporated into the soil or removed from the field. Crop residues are very important to the production of soil organic matter, reduction of soil erosion, conservation of soil water and maintenance of soil quality. The retention of crop residue is important to all soil types, but the Brown and Grey Luvisol soils of the Prairies are most vulnerable if the incorporation of crop residue is limited.

Plant carbon enters various carbon pools in the soil, and each pool varies in the rate of carbon released as CO_2. Long term storage of carbon in the soil is an important means of sequestering atmospheric CO_2-C and improving Canada's GHG emission balance. An alternative to the incorporation of crop residues into the soil is its removal from the field for use as animal feed, animal bedding or industrial products.

The most significant potential to sequester carbon derived from removed crop residues is in the production of medium density strawboard. Two plants are in production: one in Manitoba using cereal straw and the other in Alberta using fescue grass straw from forage seed production. Several other locations are currently being considered for additional plants. If surplus wheat and flax straw from the Prairies were processed as strawboard, the net carbon sequestered would equal 3.8 million tonnes of CO_2 equivalent per year. A balanced approach to support initiatives that allow the use of crop residues for industrial products without jeopardizing the organic soil carbon levels can be sustainable on the Prairies.

3.6 Water management (CO_2, N_2O and CH_4)

Current water management practices and trends were investigated relative to their impact on GHG emissions from agricultural lands. Water management was considered because it has a major impact on the land management practices and cropping systems used on Canadian farms. Water management also has a direct impact on GHG emissions because soil water content influences the timing, nature and magnitude of soil microbial processes which are responsible for the production and consumption of CO_2, CH_4 and N_2O.

A review of current practices relative to irrigation and drainage systems revealed that the statistics available from federal and provincial sources were not reliable. It was evident that adoption of irrigation and drainage practices was in response to economic returns and that wetland conservation and restoration initiatives were motivated by wildlife habitat preservation programs. Little effort has been directed toward the specific issue of change in water management relative to GHG fluxes. As was expressed in the sections regarding soil management and soil nutrient management, water management strategies affect soil carbon and nitrogen cycles and our ability to quantify flux changes in response to management changes is poor.

Wetlands and bogs represent areas of significant carbon accumulation due to high plant productivity, coupled with the inhibition of organic matter oxidation. Wetlands in Canada's agricultural zone are considered to be productive ecosystems. The net balance relative to carbon sequestration and CH_4 and N_2O production on Canadian wetlands does require study. However, data from other countries suggest that productive wetlands may represent a net sink. In some areas a promising mitigation strategy would be to return those lands that are marginal in production or that are increasingly subject to salinization to permanent cover (riparian strips) or to wetlands.

Water management policies must be evaluated from several perspectives. Policies involving the redirection of water can affect international and provincial water use patterns and agreements, can result in competition among various sectors within a specific region (i.e. urban versus agricultural uses), and can result in habitat changes downstream.

3.7 Manure management (CO_2, N_2O and CH_4)

GHG emissions from manure in Canada are estimates based largely on international guidelines from the 1996 Intergovernmental Panel on Climate Change (IPCC). The current values used for the amount of manure produced by livestock, the apportionment of manure to the various handling and storage systems, the carbon and nitrogen composition of manure, and the coefficients used for CH_4 and N_2O emissions for the various storage and land application systems, were derived using very little Canadian data. Considerable error may exist in our current estimates for GHG emissions associated with manure handling, storage and land application due to four factors:

- the high efficiencies of production within several sectors of Canada's livestock industry
- the differences in feed between countries
- the lack of inventory data on currently used handling, storage and land application facilities and equipment
- the expected effect of Canada's long cold winters on temperatures and microbial processes during manure storage

The fact that current estimates suggest as much as 13.9% of GHG emissions from primary agriculture were attributed to manure management requires the development of mitigation strategies relative to manure management. However, the fact that our current database is poor makes it difficult to target specific species or facility types within the livestock sector.

Manure can be handled and stored as a liquid (0.1–10.0% dry matter), a semi-solid (10.1–16.0% dry matter) or a solid (16.1–25.0% dry matter). Manure management guidelines in many provinces require that manure be held in storage for at least part of the year, with many large operations using year round storage facilities. The dry matter content of the manure, storage temperature, and handling and storage facilities all influence the extent of microbial decomposition and GHG emissions in the barn and during the storage phase. Once applied to land, manure nitrogen has three potential routes. It can disappear into the air, leach through the soil below the root zone, or be used by growing plants. Mitigation strategies related to land application will focus on the method, timing and optimum rates of manure incorporation to minimize GHG emissions, odor emissions and nitrate leaching. Recent experiences by livestock producers attempting to match manure application rates to soil tests revealed that traditional depths used for soil testing are too shallow.

Currently, manure management policies are handled at the municipal and provincial levels with no specific national program. Policies must recognize that infrastructure/facility changes are best made at the time of building for new farm operations or at the time of expanding existing operations. New technologies related to land application or animal management (i.e. use of nitrification inhibitors in manure or enzymes in animal feeds) can be implemented quickly once their advantages are established. Good soil nutrient management practices will focus on manure nitrogen and phosphorous. Animal management practices should include options for the reduction of total manure output as well as manure nitrogen and phosphorus output per animal unit or per unit product sold from the farm.

3.8 Sequestering carbon through shelterbelt planting (CO_2 and N_2O)

In addition to carbon sequestration there is the potential to reduce N_2O emissions by planting shelterbelts. Efforts to increase agro-forestry can directly affect GHG emissions by reducing N_2O in three ways:

- fewer field crops require less fertilizer nitrogen
- more trees means less nitrogen moving out from the root zone to surface or groundwater resources—less denitrification
- recycling the nitrogen from the tree leaves that fall reduces the need for nitrogen applied to the soil

Agro-forestry is the planting of trees on a landscape that is normally devoted exclusively to agricultural production. Shelterbelt and yard-site tree planting have the potential to trap atmospheric CO_2 and sequester carbon. Depending upon the end use, the carbon in wood products can be retained indefinitely. Estimates of marginal or degraded lands suitable for the establishment of agro-forestry systems are as high as 57,000 hectares. Some of the stands could lead to harvestable timber while other stands could lead to recreational or wildlife habitat. Upper levels for CO_2 sequestration by the above ground biomass are from 8–12 tonnes per hectare per year in Eastern Canada. Estimates are lower for Western Canada which is more arid. Few data are available for the below ground biomass or commercial scale production systems.

Agro-forestry decisions are made by the landowner. Data from Statistics Canada and the Prairie Farm Rehabilitation Administration (PFRA) show that producers have an interest in tree planting for farmyard windbreaks and linear shelterbelts, but have less interest in block planting. PFRA has provided incentives for tree planting to private landowners in the Prairies.

The loss of the grain transportation subsidy and declining grain prices have reduced the price of cropland on the Prairies, particularly in northeastern Saskatchewan. If grain production becomes economically unviable, landowners will show greater interest in agro-forestry, whether through commercial tree plantations or a reversion to the natural habitat.

Several forms of agro-forestry, most importantly, silvo-pastoralism[3] are not considered to be eligible activities under Article 3 of the Kyoto Protocol.

3.9 Biofuel production (CO_2 and N_2O)

Biofuels include a range of energy products such as waste wood and synthetic fuels such as ethanol, vegetable oil methyl esters and methanol. The four ethanol production plants in operation in Canada at the end of 1998 produced a very small portion of the total fuel consumption. However, this may change as more ethanol plants become available. Some are under construction and others are planned in Ontario, Quebec and the Prairies. Depending upon the assumptions made in the complete cycle of fuel production from grains versus gasoline, the GHG mitigation potential of switching to ethanol is estimated to range from -25% to +40%.

Processes to convert ligno-cellulosic (high fiber) materials to ethanol are less well developed compared to the processes used to convert starchy materials to ethanol. Therefore, the focus for development in the near future is with cereal grains. However, cellulosic (fiber derived) ethanol is promoted as one of the leading alternatives for reducing GHG emissions in the transportation sector in the longer term. An added consideration to using ligno-cellulosic materials in ethanol production is the potential for an increase in the demand of grains for the human food market.

Future potential for GHG mitigation through the production of biofuels needs to be assessed through complete fuel-cycle analyses. If the mitigation potentials exist for specific crop/processing/utilization systems then incentive programs can be considered.

[3] Silvo-pastoralism is the use of forested land for another form of production (e.g. pasture).

4 The economic analysis

4.1 The modelling process

The GHG reduction potential of various strategies was estimated using the Canadian Economic and Emissions Model for Agriculture (CEEMA). This model contains two sub-models: the Canadian Regional Agricultural Model (CRAM), and a Greenhouse Gas Emissions Model (GHGEM). CRAM is capable of estimating the changes in resource allocation brought about either by a change in a given technology or in various policies. CRAM is disaggregate, both for regions and for farm level enterprises. Given the current levels of the resource base (physical, human, man-made), market conditions, and existing public policy regimes, CRAM can develop an optimum allocation of resources into various enterprises and the level of consumer and producer benefits associated with the resultant allocation of resources.

GHGEM uses the current state-of-the-science of GHG emissions and the level of crop and livestock enterprises, as estimated by CRAM, to produce total GHG emissions from the agricultural sector in Canada, by province. With GHGEM, a systems approach is taken where all emissions, whether direct, indirect or induced by agricultural activities, are included.

To estimate the GHG mitigation potential, CEEMA was first used to estimate GHG emissions under two baselines: a 1990 baseline and a 2010 business-as-usual (BAU) baseline. The 2010 BAU baseline assumed no increase in the agricultural landbase, with land management practices (e.g. conservation tillage, summer fallow, fertilizer use) continuing to be adopted at rates consistent with historical trends and physical constraints. Growth in various crop and livestock enterprises for 2010 were based on projections provided by AAFC's 2007 medium term policy baseline forecast (Agriculture and Agri-Food Canada 1998). Estimated 2010 GHG emissions at the farm level suggested an increase of 2% over 1990 levels, or 8% over the Kyoto target. This relatively small increase in emissions is due to the fact that the substantial growth in GHG emissions from increased livestock production and fertilizer use are offset by agricultural soils changing from a net source to a net sink of carbon as the result of improved soil management practices. The performance of each of the mitigation strategies was compared against the 2010 BAU baseline results.

In addition to the 2010 BAU baseline, a High Export Growth scenario for the year 2010 was also analyzed. Although the original motivation for this scenario was provided by the Canadian Agricultural Marketing Council's export target of 4% of world agricultural trade, it was modified in scope to reflect higher export growth only in Western Canada[4]

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[4] This scenario is loosely framed around the Serecon Management Consulting Inc. 1999 report, which was prepared for the PFRA.

due to inconsistencies between the 4% target and the structure of CRAM. Under this scenario, Western Canada experienced growth over the 2010 BAU baseline:

- beef cows increase 17%
- market hogs increase 15%
- dairy cows increase 16%

To support the increased livestock enterprises, changes in crop production were also noted. Notable changes include a decrease in summer fallow area from 4.9 to 4.3 million hectares, and an increase in canola area from five to six million hectares. Under this scenario, fertilizer use also increased 20% of the level under the 2010 BAU baseline. All these changes resulted in a 5% increase in crop yields, and higher levels of production for various crops. Total emissions of GHGs from primary agriculture were estimated to be 13% higher than the 2010 BAU baseline.

Results of the CEEMA analysis became the starting point for the economic and non-economic impact analysis. The non-economic analysis included major health and environmental impacts of the mitigation strategies, and was primarily qualitative in nature. The economic impact analysis focused on three fronts:

- cost to producers of adopting the strategy
- economic impacts on regional economic activities and employment
- implications for the competitiveness of agricultural products

The data on changes in GHG emissions and the changes in revenues for the agricultural sector from CEEMA were compiled along with information on additional costs and adoption rates of the actions. This information was used to develop the cost per tonne of CO_2 equivalent for each action, which was then plotted on a graph along with the estimated reduction in GHG emissions. This graph allowed the development of national and provincial cost curves which can be used to identify the lower cost opportunities for reducing GHG emissions due to changes in technology and behavior.

The macroeconomic impact analysis estimates how the industrial sectors in the Canadian economy will adjust their output as the agricultural sector adopts new techniques of production or changes their output to satisfy Canada's commitment to the Kyoto Protocol. The changes to the agricultural sector identified through CEEMA are used to estimate the changes in other sectors of the economy. For example, if the agricultural sector decreases its demand for fertilizer, then the fertilizer industry will produce less fertilizer and as a result, industries that provide inputs into the fertilizer sector will decrease their industrial output. All of these changes, as well as changes in household income, are estimated by AAFC’s Input-Output Model. The model estimates the changes in the industrial output. The competitiveness analysis identified some national (regional) and international competitiveness issues related to the adoption of a given GHG mitigation strategy.

4.2 Description of mitigation strategies evaluated in Phase II[5]

Eleven mitigation strategies which represented promising opportunities emerged from the discussion of Phase I results.

Improved soil nutrient management

Farmers could practice better management of soil nutrients through the efficient application of fertilizers on crops, based on soil testing in the east, and reduced fall application in the west. Results of this simulation suggest a slight shift in the crop mix, particularly in the reduction of the corn area in Eastern Canada. Livestock production remained virtually unaffected. The direct result of this strategy was a reduction in the emissions of N_2O. Farm level GHG emissions were reduced by 1.4% from the 2010 BAU baseline. A small economic gain was noted for consumer and producer benefits.

Increased utilization of conservation tillage

The area under zero tillage in the three Prairie provinces would double the 2010 BAU baseline. A slight change in the crop mix, particularly increases in the areas under field peas and oats was noted. A significant reduction (3–8% of the 2010 BAU baseline) in GHG emissions was estimated. Potential risks related to spring soil temperatures and moisture levels however, were not considered in the simulation. Furthermore, it was assumed that producers that adopt conservation tillage do not return to conventional tillage.

Decreased summer fallow area

The area under summer fallow would decline further in the Prairies and in the Peace River region of British Colombia. In total, an additional 1.9 million hectares of summer fallow area (relative to the 2010 BAU baseline area) was reduced. Crop production on these lands was to continue as crop on stubble, which leads to increased fertilizer use. Increased crop production due to the elimination of summer fallow also results in minor price reductions, which in turn promote slight increases in livestock production. Although producers and consumers were slightly better off, the direction of change in GHG emissions was inconclusive—the estimated range was from -2% to +2% of the 2010 BAU baseline. The gains in soil carbon sequestration were offset by increased emissions from fertilizer use and livestock production. It was assumed that the amount of summer fallow in the crop rotation would be maintained at the reduced level.

Increased use of forage in crop rotations

An increased use of forage in crop rotations would lead to a shift in the crop mix, notably a decline in the area under grains and oilseeds. About 10% of the current cropland in Western Canada (about 3.1 million hectares) is planted in forage. To use the increased production of forage, national beef production increased over 50%. Swine marketings declined slightly due to increased feed grain prices as the result of lower crop production. Although consumer and producer benefits increase due to the expansion of the beef herd,

[5] More details on the results of this analysis are provided in Junkins et al. (2000).

GHG emissions increase substantially for the same reason. Hence this scenario was dropped from further analysis.

Increased area under permanent cover crops

Converting some of the marginal croplands into permanent cover crops involved about one million hectares of such lands on the Prairies. About 90% of this land was converted to improved pasture, while the other 10% was converted to hay fields. Two variants of this strategy were simulated. In one simulation no increase in the cattle herd was allowed with a GHG reduction of 2–3% of the 2010 BAU baseline. However, in the second simulation, when beef cattle were allowed to increase to utilize the increased forage production, very little reduction (0–1% of the 2010 BAU baseline) in GHG emissions was noted. Yet there was an improvement in the level of consumer and producer benefits due to increased beef production.

Optimal grazing and grassland management

To increase carbon sequestration on grasslands, three management practices were incorporated:

- decreased rate of cattle stocking on over-grazed native rangelands with supplementary feeding of animals in feedlots
- increased used of complementary grazing methods
- increased pasture acreage managed as rotational grazing land

These management practices were expected to increase biomass production and thus increase carbon sequestration in moist regions of the Prairies. The full effect of this strategy on crop mix is minor, although feed demand increases from lower stocking rates on rangelands. A 4% reduction in the GHG emissions (from the 2010 BAU baseline) is estimated under this strategy, with virtually no change in producer and consumer benefits. The scenario did not adjust production efficiencies related to improved forage quality.

Manure management

The manure management strategy attempts to decrease GHG emissions through better application of manure to cropland, and through improved storage of liquid manure. Under the former practice, fall application of manure was reduced, which resulted in a decrease in nitrogen leaching from crop production. Covering liquid manure tanks by using floating straw or balloon-type covers resulted in lower CH_4 emissions. However, in both cases, reduction in the total GHG emissions was around the 0.1–2.0% range. Given the uncertainties in the data used for this simulation, further Phase II analysis was not deemed useful.

Livestock and feeding management

Livestock feeding practices included the reduction in the dietary protein content and the inclusion of free amino acids to balance the protein. Four specific practices were used in this simulation: reduction of the protein intake of pigs, addition of phytase to pig diets, reduction of the protein intake of poultry and dairy cows, and the addition of rumen-protected amino acids for dairy cows. Both CH_4 and manure nitrogen were reduced through these measures. Reduction in the total agricultural emissions of GHGs under this strategy was around 1% of the 2010 BAU baseline.

Agro-forestry activities
Agro-forestry could account for 1% of crop land in the Prairies being converted into shelterbelts. This conversion resulted in a decrease in crop production, as well as a decrease in the number of beef cows due to increased forage prices. A reduction in the GHG emissions was estimated in the range of 3% of the 2010 BAU baseline.

Use of agricultural fibre for producing commercial products
The use of agricultural fibre for producing commercial products was not subjected to CEEMA. The sub-models (CRAM and GHGEM) would not have provided any significant new information to Phase I relative to economic considerations and GHG mitigation potential. Further Phase II analysis is underway and the results will be reported in Junkins et al. (2000).

Production of biofuels
Same as above—the production of biofuels was not subjected to CEEMA because the sub-models (CRAM and GHGEM) would not have provided any significant new information to Phase I relative to economic considerations and GHG mitigation potential. Further Phase II analysis is underway and the results will be reported in Junkins et al. (2000).

4.3 Interpretation of economic analysis

The Table views the modeling effort as a work in progress. At the time of writing this Options Report, the Table had reviewed a number of simulation results (based on CEEMA) for the BAU baseline and other strategies. As a result, the Table suggested four areas for improvements in the model development and associated information gaps:

- Proper development of the direct effects of the various strategies is an important key to the accuracy of the results.
- The present structure of CEEMA does not permit incorporating changes in production efficiencies as they relate to the scale of operation. For example, improved efficiencies related to the adoption of more advanced feeding technologies for large scale versus small scale livestock operations are not recognized. Such changes need to be provided exogenously through a change in emission coefficients.

- The emission coefficients used in CEEMA followed closely the methodology for Canadian GHG inventory of Environment Canada, with some modifications for regional agricultural conditions. However, the degree of realism for Canadian conditions remains relatively poor, and there is room for improvement which must be based on additional scientific research.

- Forecasts for future agricultural production activities by regions are driven by macro-level factors. The forecasts may not have effectively incorporated the changes in the economic and institutional environment facing specific producers in various regions.

In spite of these limitations, the modeling approach proved to be a useful tool which enabled the Table to provide a quantitative evaluation (in terms of direction and the order of magnitude) of the GHG mitigation potential if various strategies are pursued. The use of a systems approach, where all emissions linked to agricultural activities are accounted for, also offered the Table opportunities to discuss agricultural emissions in a wider Canadian context. Further work in model development is required and encouraged.

5 Challenges and opportunities for greenhouse gas mitigation policies

The agricultural sector has a great deal of potential to reduce GHG emissions. However, choosing a set of measures to realize this potential in a cost-effective way is difficult. The agricultural sector has characteristics which when taken together, set it apart from other sectors. Six characteristics shaped the Table's approach to GHG emission reduction in the agricultural sector:

- lack of knowledge—A great deal is still unknown about GHG emissions from the existing technologies used in the agricultural sector and the potential to reduce them with alternative technology. GHG emissions originate from complex biological systems that sequester CO_2 from the atmosphere but also produce CO_2, CH_4 and N_2O. GHG emissions are inherently dynamic and unstable due to the influence of weather and other environmental factors. Moreover, GHG emissions are a relatively new concern and until recently have not been the subject of much study. This lack of knowledge is in sharp contrast to the understanding in other sectors where GHG emissions are primarily CO_2 from fossil fuel use. In these sectors, energy efficiency has been studied for years and CO_2 emissions tend to be in direct proportion to fuel use.

- size—There are over 250,000 farms engaged in agriculture, spread over 50 million hectares of land, using biological processes to produce hundreds of products. The sheer number of farmers and the complexity of the systems make the monitoring and verification of individual actions very difficult and expensive. Given the limited ability to monitor individual actions, the ability to use cost-effective regulations and standards to affect behavior will also be limited.

- small profit margins—In general, the Canadian agricultural sector operates in global markets with very narrow margins and with little ability to pass additional costs on to consumers. Policies associated with GHG emissions that raise the cost of inputs directly or indirectly will adversely affect the competitiveness of the agricultural sector. From a social perspective, a reduction of income will mean the loss of farms and further depopulation of rural areas.

- trade disputes—Agricultural products have been the subject of many trade disputes. In choosing policies to reduce GHG emissions, there is a need to consider the general WTO, rules and in particular the possibility of countervail or anti-dumping duties by the United States.

- climate change—The agricultural sector could be substantially affected by climate change. The biological processes involved in agricultural production are very dependent on climate and weather. The sector must adapt to these changes if it is to survive. Unfortunately, information is lacking as to how, when or where climate change will manifest itself and how world agricultural markets will be affected. Thus climate adaptability must be an important consideration for policy and technology choices in the sector.

- policy making—The process of policy making in agriculture differs from other sectors. Agriculture is a shared federal-provincial responsibility in the Canadian Constitution. However, many environmental regulations and standards are set by local municipal governments. Farm organizations also play an active role in the formation of policy at all three levels of government.

The combination of these six characteristics makes it difficult to design appropriate policies for GHG reduction in the agricultural sector. The policies cannot require monitoring and verification of individual actions, nor can they involve large increases in the cost of production. Given these limitations, the most viable means of achieving GHG reduction will be to create and to promote technologies that increase profitability and that can be voluntarily adopted. While such technologies do exist, it is important to discover and to develop new and profitable GHG-reducing technologies.

Fortunately, the agricultural sector has many examples where research has created technologies that the sector adopted. In livestock production, nutrition management and grazing systems were developed and adopted by much of the sector. In crop production, new grain varieties and crops are continually being developed by research and adopted by the sector. The zero tillage practices were developed out of a desire by producers, policy makers, and industry to reduce soil erosion. In the case of zero tillage, 25 years of development created cost-effective technologies that are widely adopted in the sector. Given these past successes, a sustained research and development effort by the agricultural sector will very likely result in the creation of many technologies that will be adopted in the sector if the benefits are well demonstrated.

5.1 The stages of technology development

Technologies typically develop through several stages between the identification of a need and the final adoption of the new technology to address the need. The national process has identified a need to reduce GHG emissions from the agricultural sector. Achieving cost-effective GHG reduction in the sector will involve the adoption of new technologies. Starting with an objective or identified problem, the stages of technology development continue with ideas and move through prototypes to commercial applications and to adoption and verification (Figure 2).

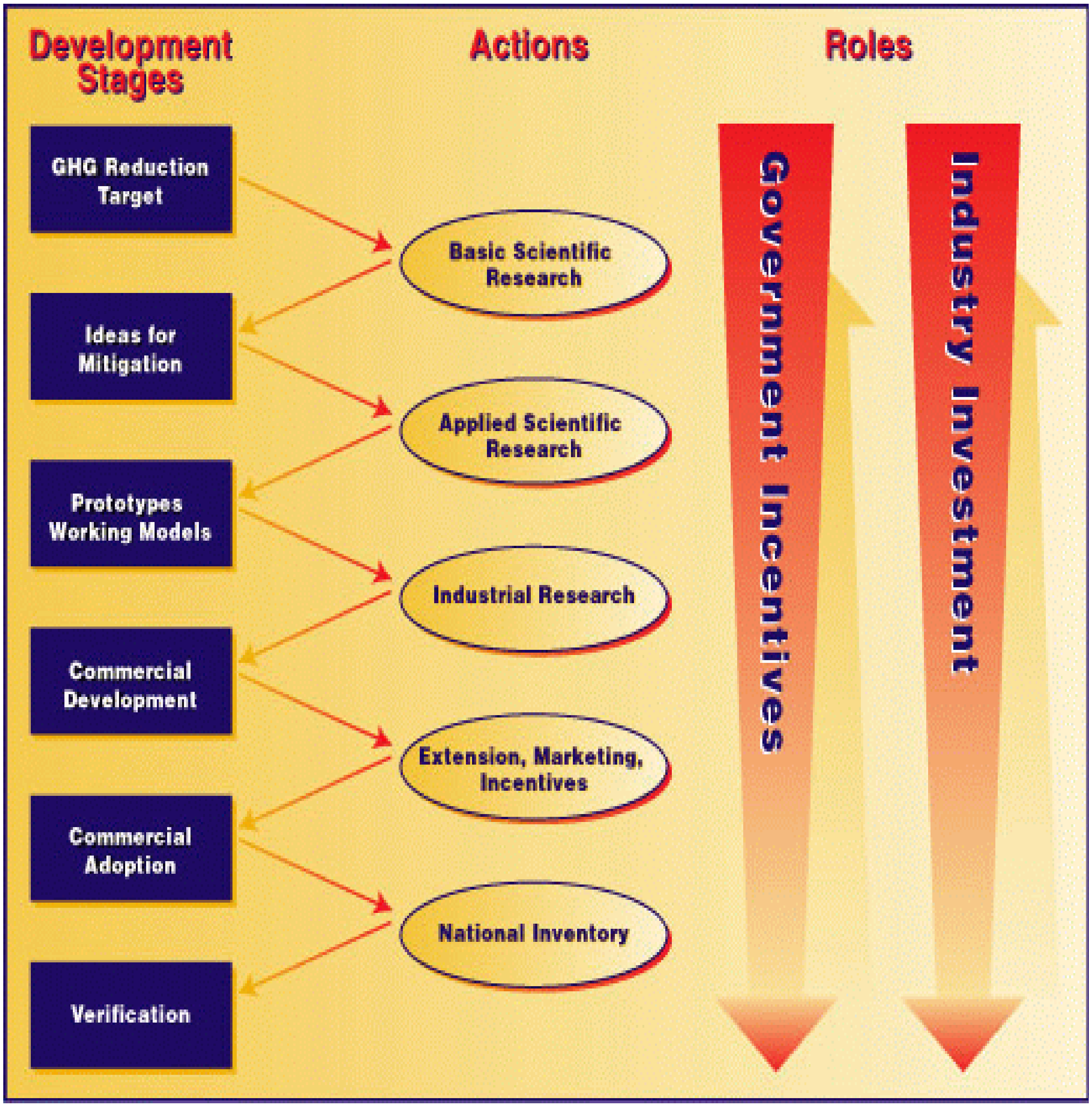

Figure 2: Development Stages, Actions and Roles in technology Development

5.2 The actions between stages

To move from one stage to the next in technology development requires specific actions. Five actions are illustrated in Figure 2. The actions necessary to bring about the adoption of new technologies will depend very much on what stage of development the technology is in. For instance, while a commercially proven technology may only require marketing and extension, a new idea may require scientific research, industrial research, plus marketing and extension activities.

5.3 The role of governments and industry

The process of development and adoption of GHG-reducing technologies requires a mixture of government and industry actions. At this point GHG emissions are non-market products of production, that is GHG emissions have no value in the market place. However, upon weighing a preponderance of scientific evidence, many people have come to the conclusion that GHG emissions do have potentially serious environmental costs associated with them. Governments, attempting to reflect the view of their people, have signed the Kyoto Protocol, and have pledged to implement policies to reduce GHG emissions. Without this government action, markets would fail to reduce GHG emissions. Thus government policy is inextricably linked to GHG reduction.

Finding the best role for governments in reducing GHG emissions is a very complex problem. Ideally, they should create policies that accomplish GHG-reduction objectives at the least economic and social cost to the country. The least cost policies will depend on many factors, including both the efficiency and the distributional effects of the policies. In the agricultural sector the problem is especially complex. The characteristics of the sector limit the ability of governments to use regulations and taxes to stimulate the sector to develop new technologies. Rather, governments must offer to assist in the development and adoption of technologies that reduce GHG emissions and are economically attractive to producers.

In the development process, governments must assist only where markets are likely to fail in providing adequate incentives. Market failure in the development process can occur at several stages depending on the type of technology being developed. In general, the further a product is from commercial adoption, the more reluctant firms will be to invest in its development. Most private technology development suffers the greatest loss at the basic research level. At this level of development, concepts are still vague, the potential for commercial adoption is remote, and there is a very limited ability to prevent “copy cat” technologies. As development moves down the development chain toward commercial prototypes, the ability to capture the value of research generally increases. As commercial products are produced and protected by patents, the industry has a significant potential to capture the benefits.

The exception to this rule involves the creation and dissemination of information and ideas which cannot be captured by specific firms. This capture can be a problem at any stage of development. For example, if a firm pays for extension activities that extol the general virtues of zero tillage, other firms selling competitive products can “free ride” and capture the benefits of the marketing investment. Given this free rider problem, firms will tend to under-invest in public extension activities which may be critical for GHG adoption.

For the numerous areas where GHG-reduction technologies are not known, the process must begin with two forms of research into the GHG effects:

- an investigation of the wide range of technologies that are currently in place

- the development of new technologies

The industry can play a very large role in directing the research and promoting the adoption of GHG-reducing technologies. However to play this role, there must at least be some modest incentives to do so.

5.4 The timing of policies

The optimal timing of policies to bring about GHG reduction is a very important consideration. While immediate action will reduce global GHG emissions, reductions prior to 2008 will not explicitly contribute to meeting Canada's Kyoto target. It is also true that many processes, particularly the development of new technologies, take many years, thus immediate action may be required.

A timing issue of critical importance is the treatment of sinks. If sinks are eventually included in the implementation of the Kyoto Protocol but early action is not rewarded, this combination could create a perverse incentive to "empty" the sinks prior to 2008 with the hope of getting paid to fill the sinks after 2008. A related issue is if sinks can be filled only once, then given the uncertainty about future climate effects and GHG policies, should these sinks be filled now or later, perhaps at a more critical date?

Finally, the willingness of the private sector to invest in GHG-reducing technologies will be very dependent on the degree of commitment of governments. Uncertainty about future incentives creates a present incentive to delay investment until more information is available. In the case where there is going to be a long delay between investment and the adoption of technologies, this uncertainty will postpone agriculture's contribution to GHG reduction.

6 What we found

The Table undertook an extensive and systematic search yet identified few actions that with certainty could significantly reduce GHG emissions from the agricultural sector at a low cost. In most cases very little was known about the affect of alternative technologies or about the economic costs of the technologies. It became abundantly clear that more research was required to evaluate these technologies and to discover other technologies that could be even more effective in reducing GHG emissions.

The technologies that showed some verifiable low cost reduction in GHG emissions involved the sequestering of carbon. Several technologies showed promise for net GHG emission reduction and could contribute to Canada's Kyoto commitment if such sinks are eventually included in the agreement. The Table identified three areas:

- increased zero tillage, reduced summer fallow, improved grazing strategies, and conversion of cropland to wildlife habitat—soil sinks
- agro-forestry and shelterbelts—forestry sinks
- strawboard and other fiber manufacture—industrial sinks

If Canada is committed to GHG reduction regardless of Kyoto acceptance, these technologies are well enough known to be promoted actively. The research required for technologies is social science research into market and non-market mechanisms that can be used to increase the rate of adoption. As well, further study is required into the optimal timing of the policies.

There were many other areas which had potential to reduce GHG emissions but there was uncertainty about the effects of specific technologies or more importantly, the optimal technologies to employ. This uncertainty suggests the technology is at an early stage of development and more basic and applied research is required before specific technologies are promoted. In this case the design of the incentives to do research is important. The areas of potential at this stage of development include crop nutrient management, livestock nutrient management, manure management and biofuels.

The bottom line is that although many technologies show some promise, there is no apparent "magic bullet" in the arsenal to reduce agricultural GHG emissions to 6% below the 1990 levels. The good news is that unlike energy conservation, the research directed toward GHG reduction in the agricultural sector is still in a very preliminary phase—this problem is a new one. At this time not enough is known about the effects of many technologies that are in use today. A study of these systems will lead to a better understanding of the processes and the refinement of the best current technologies toward even more efficient technologies in the future. There are also many outstanding issues about the best private and public institutions to achieve cost-effective GHG reduction, which suggests a need for continued policy development.

Reducing GHG emissions alone is unlikely to result in dramatic shifts in production practices. There is however, a strong synergy between these practices and those that address other environmental issues for the agricultural sector. Six such environmental issues include:

- reducing CH_4 emissions from animals would also have positive effects on animal feed conversion efficiency

- reducing CH_4 emissions from manure storage would result in odor reduction, one of the primary issues in the location of manure storage facilities

- reducing N_2O emissions from fertilizers and animal manures by seeking methods to increase nutrient use efficiency which will reduce nitrate leaching to groundwater and decrease expenditures on fertilizer

- reducing N_2O emissions from manure by reducing the overall nitrogen content of manure through the development of improved feeding strategies that have other environmental and economic benefits such as reduced phosphorus content of manure and more efficient use of animal feeds

- sequestering soil carbon by increasing soil organic matter will result in increased soil quality which has numerous agronomic implications including increased fertility, improved water holding capacity, reduced susceptibility to wind and water erosion, and increased soil bio-diversity

- increased soil sequestration from shelterbelts, and reduced summer fallow would increase the value of farmland for wildlife habitat

Thus efforts to reduce GHG emissions from the agricultural sector will support current and future efforts to address these other environmental issues.

7 The road forward

7.1 Implementing the process

The recommendations in this report suggest how governments can create an environment to foster net GHG reduction in the agricultural sector at a minimal economic cost to the sector and to the Canadian economy as a whole. The recommendations are supported in the body of the report with a description of the analytic approach of the Table and the scientific and economic rationale the Table used to develop them.

The reduction in GHG emissions will require both government and industry action. Some research and development resources provided by governments can create the potential for the industry to benefit from adopting better technologies. An informed industry will also recognize that given the importance of the environment in international markets, and the potential to trade emission reductions, developing an industry with low GHG emissions may be good business. Finally, the government should reiterate its commitment to the reduction targets and infer that any sector that does not find ways to contribute to GHG reduction could face compulsory measures at some point in the future.

The recommendations represent the output from a 16-month process of research and deliberation by the Table. They provide a framework for the national strategy for the cost-effective reduction of net GHG emissions in the agricultural sector. The human and social capital base embodied in this Table is a considerable resource that could be consulted in the further refinement and operation of GHG strategies.

Many of the recommendations should be initiated immediately and simultaneously to have a real impact by the 2008–2012 commitment period. As prescribed by the national process the first two recommendations are early action ones and should be taken immediately to reduce net GHG emissions. These early action items encourage technologies that are clearly cost effective means of GHG reduction.

The other recommendations deal with processes that take several years to produce results. Research takes time. The sooner research commences the sooner results will be produced. The same timing issue exists with extension programs—the process of adoption takes time. There must be an effort to engage the industry in developing and pursuing the best management practices for GHG reduction as soon as possible. This effort is especially critical for those individuals in the sector that are expanding now and investing in the technology that they will use in 2008. The urgency to commence work on many fronts suggests the need for an immediate commitment of resources and the need for an immediate and concerted effort to create the institutions and policies to allocate these resources. Delays in these initiatives will limit the ability to reduce GHG emissions in the commitment period.

7.2 Recommendations

Recommendation 1. Governments should provide resources to assist the extension of knowledge required to foster the adoption of proven technologies. For example, governments should work with the industry to encourage the adoption of improved grazing management systems, feeding strategies, and zero tillage cropping systems.

The activities should include the development of benchmarks for producer-to-producer comparisons, the support for producer groups in extension, and the creation of general public awareness of GHG issues. In general, improvements in production efficiency will reduce net GHG emissions. Initial efforts should focus more toward creating a general awareness of the GHG issues and the promotion of overall production efficiency, while later efforts should help the industry better understand specific technologies and GHG effects.

Recommendation 2. In recognition of the public benefits where cost-effective technologies are well known and an economic incentive is required for their adoption, governments should provide public incentives for the adoption of GHG-reducing technologies. These public incentives would stay in place until markets for emission reductions in the agricultural sector are established. For example, governments should work with the industry to develop financial incentives for the planting of shelterbelts.

It can be cost-effective for governments to provide some economic incentives for adoption in the agricultural sector when they are facing larger expenditures in other sectors to accomplish the same amount of GHG reduction.

Recommendation 3. The federal government should continue to insist on the inclusion of soil, forestry and industrial sinks in the Kyoto Protocol and to ensure that the IPCC guidelines reflect Canadian conditions.

As a party to the Kyoto Protocol, the federal government must continue to lobby for the inclusion of sinks in the Protocol. Sinks are an important component of the agricultural sector’s contribution to the global GHG solution.

Recommendation 4. Governments should create research funds managed by the agricultural sector to assist in research and development of applied technologies for GHG reduction.

Direct involvement of the agricultural sector in the development of technology ensures the technology will take advantage of the knowledge within the sector and at the same time make the sector aware of the GHG issues and opportunities. Public funds should continue until there are sufficient private incentives for these activities.

Recommendation 5. Governments should provide public resources to support basic research activities for net GHG reduction particularly in the areas of crop nutrient management, livestock nutrient management, manure management, carbon sequestration and biofuels.

Public resources should be allocated toward research activities that would not normally come from the private sector. The research activities could involve basic scientific research leading to a greater understanding of the processes involved in GHG emissions, research into potential breakthrough technologies with many years to commercial adoption, and the creation of networks or centers to coordinate and share the research that is done across sectors, provinces and countries. The monies should be spent on a portfolio of activities with different payoff times and expected outcomes. While some industry input would be desirable, scientific expertise would be essential in this allocation process.

Recommendation 6. As part of a national strategy, governments should work with the agricultural sector to refine national inventory, measurement and verification systems for net GHG emissions and to reflect improvements in technology. Monitoring should include the collection of more accurate raw data and the refinement of analytical models that can be used to manage and to assess the effectiveness of GHG-reduction policies.

Getting international acknowledgement for net GHG emissions from the agricultural sector will be dependent on the ability to verify reductions. Some of the verification process must involve modelling. Research resources are required to create more accurate models. There is a need for accuracy and transparency in the verification and modeling system and therefore this should be done at arm’s length from any potential political influence.

Recommendation 7. As part of the national process, where possible, GHG emission trends in all sectors of agriculture in all provinces should be monitored and published.

This recommendation is intended to create a general awareness of GHG emissions within each sector of Canadian agriculture. The information will build public support for those sectors that accomplish GHG reduction and put some pressure on other sectors to reduce GHG emissions. There is a need for accuracy and transparency in the reporting and as such the reporting should be done at arm’s length from any potential political influence.

Recommendation 8. Governments should work with the agricultural sector to develop targets for the reduction of GHG emissions along with incentives for meeting the targets.

Strong industry input is needed in the development of GHG emission targets. Having defined targets will focus the effort to reduce GHG emissions.

Recommendation 9. Governments should assist the agricultural sector in the development and refinement of best management practices for the reduction of GHG emissions.

This recommendation would involve benchmarking current technologies with an in-depth analysis of GHG emissions from existing technologies. Having established GHG effects this information should be combined with crop and livestock nutrition management plans. These activities would require some government money to overcome the public good problem and would require close industry cooperation. These benchmarking funds could be controlled by industry groups with a copy of the results of the research provided to a central body for overall coordination and the broad dissemination of results.

Recommendation 10. Governments should provide resources to assist policy research, market research, legal research and other public infrastructure to facilitate the development of trading mechanisms that reward reductions in net agricultural GHG emissions.

In the end, enabling market mechanisms for reduced GHG emissions is important since they will provide strong incentives for the private sector to develop and adopt GHG reducing technologies. The government must play a role in creating the legal and policy framework for these markets.

Recommendation 11. Governments should co-operate with private sector partners to develop a strategy that will enhance the agricultural sector's ability to adapt to climate change using sustainable farming systems.

Even if implemented, the Kyoto commitments will not halt the accumulation of GHGs in the atmosphere—some amount of climate change is inevitable. It is in the interest of the agricultural sector to develop a long run strategy to enhance the sector's flexibility to adapt to climate change. This adaptation will reduce the sector's vulnerability and increase its ability to capitalize on opportunities as they emerge.

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Forthcoming:

Junkins, B., S. Kulshreshtha, P. Thomassin, A. Weersink, K. Parton, R. Desjardins, M. Boehm, R. Gill, C. Dauncey. "Analysis of strategies for reducing greenhouse gas emissions from Canadian agriculture." Technical report to the Agriculture and Agri-Food Table. Policy Branch, Ottawa: AAFC, 2000.

Appendix A

Agriculture and Agri-Food Table Membership.

Member	Organization
Co-chairs	
Les Haley	Agriculture and Agri-Food Canada
Garth Sundeen	Canadian Federation of Agriculture
Members	
André Bédard/ Jean-Paul Lussia-Berdou	Québec Ministère de l'Agriculture, des Pêcheries et de l'Alimentation
Jean Brodeur	Cooperative Fédérée du Québec
Jim Bruce	Soil and Water Conservation Society
David Burton	Canadian Society of Soil Science
Jean Louis Daigle/ Gordon Fairchild	Eastern Canada Soil and Water Conservation Centre
Peter Dzikowski	Alberta Agriculture, Food and Rural Development
Jim Farrell/ John Harapiak	Canadian Fertilizer Institute
Sheila Forsyth	National Agriculture Environment Committee
Alexandre Lefebvre/ Eric Aubin	Canadian Pork Council
Richard Gray	University of Saskatchewan
Suren Kulshreshtha	Agriculture and Agri-Food Canada
Daniel Masse	Agriculture and Agri-Food Canada
Douglas Mutch	Canada Grains Council
Katharine Schmidt/ Susan Antler	Food and Consumer Products Manufacturers of Canada
Paul Smith	New Brunswick Department of Agriculture and Rural Development
Peggy Strankman	Canadian Cattlemen's Association
Ed Tyrchniewicz	International Institute for Sustainable Development
Karin Wittenberg	University of Manitoba
Nigel Wood	Ontario Ministry of Agriculture, Food and Rural Affairs
Brian Yusishen	Manitoba Agriculture
National Climate Change Secretariat	

Appendix B

Meeting dates and locations for the Agriculture and Agri-Food Table.

Date	*Event/Location*	Outcome(s)
June 30, 1998	Table Pre-Meeting, Toronto, ON	
September 9, 1998	Winnipeg-Ottawa (Video conference)	• Identification of areas for further study • Discussion of Early Action items
October 23, 1998	Winnipeg, MB	• First review of the Foundation Paper • Update on Early Action proposal, • Presentation by PAMI
November 19 & 20, 1998	Montreal, QC	• Presentation and discussion of commissioned papers • Collaboration with Forestry Table initiated
December 14 & 15, 1998	Calgary, AB	• Prioritization of measures for Phase I analysis • Identification of Phase I contract teams • Decision to contract Food Processing Foundation Paper • Presentation by PFRA, Alberta Food Processing Industry, Canadian Fertilizer Institute, Public Outreach & Education, Modeling and Analysis Group
January 27, 1999	Hull, QC	• Presentation on GHG Emissions Inventory, Emission Trading • BIOCAP Presentation • Discussion of Phase II modeling
February 19, 1999		RFPs for Phase I Studies Issued
	(Conference call)	Sub-committee established for Options Paper
April 6 & 7, 1999	Winnipeg, MB	• Final review of Foundation Paper • Report Enhanced Voluntary Action Table, Sinks Table
May 6 & 7, 1999	Ottawa, ON	• Contractors for Phase I studies announced • Presentation on Emissions Trading • Phase I Reports – Nutrient Management, Soil Management & Manure Management • Sinks Table Sub-committee Report • Presentation Adaptation in Agriculture

June 9-11, 1999	Truro, NS	• Presentation of remaining Phase I studies • Selection of options to go forward to Stage II of Phase I. • Presentation on Phase II analysis.
July 22 & 23, 1999	Ottawa, ON	• Consideration of Phase II analysis • Development of Options Paper
Aug. 26 & 27, 1999	Ottawa, ON	• Consideration of Phase II analysis • Development of Options Paper
October 15, 1999	Ottawa, ON	• Presentation of Options Paper • Evaluation of Actions and Measures
November 15, 1999	Toronto, ON	• Discussion of Options Paper
November 30, 1999	Conference call	• Final approval of Options Paper

Appendix C

Expert Papers presented at the Montreal meeting of the Agriculture and Agri-Food Table. Full text articles available from Agriculture and Agri-Food Canada's Environment Bureau. Abstracts are available on the world wide web at :
(http://aceis.agr.ca/policy/environment/sustainability/stewardship/climate_change/table/abstract.html)

Title	Authors
Greenhouse Gas Emissions from Agriculture and the Canadian Commitment at Kyoto	Charles Mrena
Land Use and Climate Change	Charles Mrena
Nitrous Oxide Emissions from Canadian Agroecosystems: Understanding the Process	R.L. Lemke, P. Rochette, and E. VanBochove
Developing methods to predict N_2O emissions in crop production systems	W.N. Smith, R. Lemke, R.L. Desjardins
Quantifying, predicting and verifying changes in soil carbon	B.H. Ellert
Validating Greenhouse Gas Flux Estimates from Agroecosystems	E. Pattey and R.L. Desjardins
IPCC Greenhouse Gas Accounting and Agriculture	Marie Boehm and Ira Altman
The Economics Of Reduced Tillage And Reduced Summer Fallow In Crop Production In Canada: A Review Of Available Evidence	Michael Rossetti and Glenn Fox
Economics of Biofuels	Ewen Coxworth and Andre Hucq
Greenhouse Gas Emissions From Manure and Measures For Their Mitigation	Daniel I. Massé and Francis Croteau
Potential For Reducing GHG Emissions From Domestic Monogastric Animals	Candido Pomar
Rangeland Cattle Production And The Greenhouse Effect, A Review	J.C. Kopp and K.M. Wittenberg
Ruminant Livestock Methane Emissions: Potential for Mitigation	D. Boadi and K.M. Wittenberg
Livestock Manure Management Systems and Greenhouse Gases Production	Sylvio Tessier and Alfred Marquis
The Economics Of Modified Manure Handling Systems For Greenhouse Gas Reductions	Gregory De Vos, Alfons Weersink, Peter Stonehouse
The Economic Feasibility of Modified Feed and Rumen Management to Reduce GHG Emissions	Scott R. Jeffrey
Adapting to Climate Change in Canadian Agriculture	Allen Tyrchniewicz
How Will Greenhouse Gas Policy Affect The Competitiveness Of Canadian Agriculture	Allen Tyrchniewicz
Complimentarities And Conflicts In Policies Relating To GHG Emissions And Agriculture	Edward Tyrchniewicz
Clean Development Mechanisms And Agriculture	Edward Tyrchniewicz
Non-Market Policy Instrument Options For Reduced GHG Emissions From Agriculture	Don Buckingham and Cynthia Kallio Edwards
Incentives For Early Action And Timing Of Greenhouse Gas Policies For Agriculture	Richard Gray and Dan Monchuk
Market Instruments Options For Reduced GHG Emissions from Agriculture	Allen Tyrchniewicz

Appendix D

Tables 1–9 represent mitigation technologies and strategies that were presented to the Agriculture and Agri-Food Climate Change Table for consideration in the process of developing the Options Report and its recommendations.

TABLE 1. SUMMARY OF GHG MITIGATION TECHNOLOGIES AND STRATEGIES CONSIDERED AGRICULTURE GRASSLANDS

GHG mitigation action/technology	Potential GHG mitigation (Tonne of CO_2 equivalent per year) using a 20-year average	Barriers to adoption		
		Technology not ready for commercial use or uncertain mitigation potential	Adverse economic consequences	Adverse environmental or health consequences
Improved grazing management on native grasslands-strategic dietary supplementation. (10)*				
Improved grazing management on native rangeland-complementary grazing. (7)	139,985,750			
Improved grazing management on native rangeland-reduced stocking rates. (7)	342,464,550		Increased production costs	
Increased rotational grazing on natural pastures of Eastern Canada. (7)	34,929,550			
Rotationally grazing tame pastures in Atlantic Maritime, Mixed Wood Plains and Pacific Maritime regions. (7)	17.7		Producers need to become better pasture managers	
Covering highly eroded crop land with permanent grass. (7)	126.6			
Increasing forages in rotation from 50% to 70%. (7)	448		Reduced annual crops and potential excess of forage	

***numbers in brackets coincide with references**

Conversion of alfalfa land in Aspen Parkland/Boreal Transition Region to native rangeland. (7)	269			Reduced income in the target areas
Converting away from commercial Nitrogen towards manure Nitrogen sources for hay land fertilization. (7)	26,794			
Optimizing soil fertility and grazing management on tame pastures in Western Canada. (7)	38.1			
Introduction of grass legume mixtures and rotational grazing of tame pastures in the Boreal Shield, Montane Cordillera, Aspen Parkland/Boreal Transition and Peace River Lowland. (7)	32.2		Increased cost of production	
Reduced stocking rate on over-grazed tame pastures in the dry prairie regions. (7)	14.5			

TABLE 2. SUMMARY OF GHG MITIGATION TECHNOLOGIES AND STRATEGIES CONSIDERED
SOIL MANAGEMENT OF CULTIVATED LANDS

GHG mitigation action/technology	Potential GHG mitigation (Tonne of CO_2 equivalent per year)	Barriers to adoption		
		Technology not ready for commercial use or uncertain mitigation potential	Adverse economic consequences	Adverse environmental or health consequences
Development of innovative practices for deep placement of Carbon.				
Increased research to reduce risk and increase production when using reduced tillage practices.				
Develop baseline data; quantify emissions from all sources; and conduct comparisons of management scenarios in the various regions of Canada. Models need to be refined by incorporating accurate data and should be focused on both CO_2 and N_2O. Existing models include Expert-N, CENTURY model, DeNitrification DeComposition model, and ECOSYS. (16)				
Rather than devoting a high level of resources toward trying to measure soil Carbon and soil Carbon change, which will then be used to develop complicated models with a high degree of uncertainty, we should focus on criteria that serve as indicators or criteria to determine loss or gain of soil Carbon; i.e. a measure of plant biomass returning to the soil annually.				

Reduce the practice of crop residue burning and encourage over-winter residue.	Low	Net effect on GHG mitigation not known	Increased field crop disease problems—suited to medium and coarse soils only	
Application of manure and sewage sludge on land as nutrient source.		Net effect on GHG mitigation not known		
Expand access to soil testing and encourage precision farming.		Should reduce N_2O emissions, but extent not known	Increased production costs	
Increase land acreage that is farmed using minimum or zero tillage.	110,000–2,468,000	Ability to measure soil Carbon gains is difficult—limited regional data relative to differences for N_2O emissions from various tillage systems`	May affect emergence and development of plants for certain crops in Eastern Canada due to cooler spring soils	A shift to increased herbicide use
Reduction of summerfallow.	188,000–662,000		Increased risk of poor yields in more arid regions—increased fertilizer and herbicide requirements	

TABLE 3. SUMMARY OF GHG MITIGATION TECHNOLOGIES AND STRATEGIES CONSIDERED

SOIL NUTRIENT MANAGEMENT

GHG mitigation action/technology	Potential GHG mitigation (Tonne of CO_2 equivalent per year)	Barriers to adoption		
		Technology not ready for commercial use or uncertain mitigation potential	Adverse economic consequences	Adverse environmental or health consequences
Determine the impact of fertilizer form and placement, legume crops, and tillage systems on N_2O emissions with particular emphasis on their interactions. (16, 14)				
Understand the controls and mechanisms of spring thaw and over-winter emission for N_2O and develop low emission strategies for various regions in Canada. (14)		—		
Determine the ratios of N_2O produced per unit of NH_4^+ or NO_3^- denitrified. (14)				
Quantify agricultural contributions to off-site N_2O emissions. (14)				
Partition of sources of N_2O emissions. (14)				
Determine the relationship between soil texture and annual N_2O losses. (9)				
Soil test at seeding and adopt a 20 kilogram per hectare reduction in Nitrogen application on corn in Ontario. (9)	136,400	Confirm at response curves local level	$6.00 per hectare revenue loss	

Reduced fall Nitrogen application in the Prairies and Peace River region of British Columbia. (9)	589–1,209	Don't know current fall application rates Don't know change in N_2O emissions if application timing changes Requires a broad-based technical information and transfer program for targeted regions and crops	Decreases window for field work Low fall fertilizer values not realized Fertilizer supply industry will require tighter production, storage and delivery scheduling	
Adjust Nitrogen application to a more efficient portion of the yield curve in Atlantic Canada by: • decreasing N application to the crop following potatoes, • split application of N on potatoes • environmental reduction on potatoes. (9) in Quebec by: • using soil and stalk tests to match better the applications to crop requirements. (9)		Requires soil nitrate and stalk testing ability Develop response curves at local level		
Minimize the concentration of NO_3 in the soil solution over winter and during spring thaw by: • using cover crops after harvest • incorporation of crop residue with a high Carbon: Nitrogen ratio • using intercrops • using variable rate technology in hummocky topography to match applied Nitrogen to yield		Need quantitative estimates of the impacts of various mitigation technologies on regional basis		

Managing application of high rates of manure Nitrogen in the spring and fall in British Columbia. (9)	1,271,000–26,350,000	Don't know current fall application patterns Introduce broad-based technical information and transfer program for targeted regions and crops Develop better quantitative estimates of N_2O reductions with change in practice		
Maintain conditions of good aeration and manage soluble carbon and water to minimize conditions of denitrification by: • shallow incorporation of manure • uniform distribution of N • management of crop residue • soil pH adjustment to reduce rate of denitrification. (8)				
Timing Nitrogen availability to match crop requirements by: • development and use of controlled release fertilizers • development and use of urease and nitrification inhibitors • increase use of split applications of fertilizer N (side dressing) • use of legumes in rotations. (9)				

Managing depth of denitrification and nitrification processes. (9)				
Manage carbon from manure, compost, legume residue and other crop residue. (8)				

TABLE 4. SUMMARY OF GHG MITIGATION TECHNOLOGIES AND STRATEGIES CONSIDERED
LIVESTOCK FEEDING & MANAGEMENT

GHG mitigation action/technology	Potential GHG mitigation (Tonne of CO_2 equivalent per year)	Barriers to adoption		
		Technology not ready for commercial use or uncertain mitigation potential	Adverse economic consequences	Adverse environmental or health consequences
Increased use of production enhancing agents to reduce GHG emissions per unit of product from dairy, beef and other ruminants. (10)				—
Improved animal management to reduce GHG emissions per unit product from all livestock production systems. • improved genetics • improved reproduction • controlling disease. (10, 15)				—
Develop database for enteric emissions from ruminant animals in Canadian production systems. (10, 13)				
Improve growth performance of pigs by 10%. (1)	6,300–12,642 and manure Nitrogen output by 16,833,000–33,666,000 tonnes per year	Genetic potential of pig is not known	May increase production costs	May compromise animal welfare

Add phytate to pig diets. (1)	6,300–12,642 and manure Nitrogen output by 14,896,000–29,793,000 tonnes per year	Research to verify the high animal response to phytase in Canadian systems.	May increase production costs	
Market boars instead of barrows. (1)	3,906–7,791 and manure Nitrogen output by 7,368,000–14,736,000 tonnes per year	Research into feeding boars required Research to minimize boar taint required	Legalize slaughter of intact male pigs required	Food quality issue related to boar taint
Reduce non-starch polysaccharide intake by 10%. (1)	13,356–26,775	Results from enzyme use are not consistent		
Reduce dietary protein by 15% for all poultry diets. (1)	reduce manure Nitrogen output by 7,55–15,105 tonnes per year		May increase production costs	
Improve feed efficiency in poultry by 15%. (1)	manure Nitrogen output by 2,514–5029 tonnes per year		May increase production costs	
Improve performance of poultry barns by 5%. (1)	manure Nitrogen output by 951–1,903 tonnes per year		Would target the least efficient operations	
Addition of â-glucanase to poultry diets. (1)	283–565 and manure Nitrogen output by 951–1903 tonnes per year			

Reduce dietary Nitrogen in ruminant diets. (1)	manure Nitrogen output by 14,700–22,700 tonnes per year		May increase production costs	
Increase rate of gain in weaned beef calves during the backgrounding phase. (1)	0		Match calving time and marketing time more closely	Encourages greater use of feedlot feeding with negative impacts on people living close to feedlots
Increase growth rate of weaned calves. (1)	716,000–964,000 and manure Nitrogen output by 7,200–9,700 tonnes per year		Trade issues regarding use of implants	Increased use of implants Reduced manure Phosphorous output
Increase milk production using, for example, growth hormone. (1)	22,000–44,000 and manure Nitrogen output by 2,000–4,000 tonnes per year	BST not approved for use in Canada	Improved feed efficiency	Reduced manure Phosphorous output
Improve feed efficiency in cattle using, for example, ionophores. (1)	196,000–723,000 and manure Nitrogen output by 1,900–6,900 tonnes per year	Long term potential to directly reduce CH_4 emissions has not been validated at a commercial scale	Improved feed efficiency	Reduced manure Phosphorous output

Improve forage quality. (1)	315,000–917,000 and manure Nitrogen output by 8,900–14,500 tonnes per year	On farm technology to rapidly estimate forage digestibility and quality		
Reducing fat content in market cattle and milk can reduce GHG emissions if a severe policy change is implemented. Otherwise major increases in emissions are expected with recent grading changes in the Canadian system. (1)	478,000 and manure Nitrogen output by 5000 tonnes per year	Low fat meat is undesirable due to palatability and tenderness issues	Reduced production costs. Potentially higher processing costs	Reduce fat content in our diets
Improved reproductive performance in cattle. (1)	407,000–762,000 and manure Nitrogen output by 4000–7400 tonnes per year	Commercial advancement of genetic and reproduction technologies		
Increasing the incidence of twinning in cattle. (1)	22,000–62,000 and manure Nitrogen output by 200–500 tonnes per year	Need to develop cattle lines that can regularly produce twins with minimal calving problems		
Use of specific methane inhibitors (i.e. bromochloromethane complexed with cyclodextrin or amichloral hydrate). (1)	7,506,000	No compounds currently registered for use Effect of inhibitors on animal performance and product quality are not known		Potential public resistance to widespread use of chemical inhibitors

Addition of nitrates to ruminant diets as a competitive methane inhibitor. (1)	129,000–165,000	Can be toxic, need to research optimum levels		May cause small increases in manure N output
Addition of malate to ruminant diets. (1)	71,000– 263,000 and manure Nitrogen output by 700–2700 tonnes per year	Technology is in experimental stage		

TABLE 5. SUMMARY OF GHG MITIGATION TECHNOLOGIES AND STRATEGIES CONSIDERED
CARBON SEQUESTRATION THROUGH USE OF CROP RESIDUE FOR INDUSTRIAL PRODUCTS

GHG mitigation action/technology	Potential GHG mitigation (Tonne of CO_2 equivalent per year)	Barriers to adoption		
		Technology not ready for commercial use or uncertain mitigation potential	Adverse economic consequences	Adverse environmental or health consequences
Use surplus straw from forage seed and wheat production for strawboard manufacture. (2)	3,544,164			Should be avoided in Brown and Gray Luvisolic soil zones due to erosion
Use flax straw in the production of industrial plastic composites. (2)	295,068	Net GHG savings not known		
Use straw for construction of straw bale houses. (2)			Alternatives to build energy efficient houses exist with other high Carbon materials	

TABLE 6. SUMMARY OF GHG MITIGATION TECHNOLOGIES AND STRATEGIES CONSIDERED WATER MANAGEMENT IN AGRICULTURE

GHG mitigation action/technology	Potential GHG mitigation (Tonne of CO_2 equivalent per year)	Barriers to adoption		
		Technology not ready for commercial use or uncertain mitigation potential	Adverse economic consequences	Adverse environmental or health consequences
Increase use of irrigation in British Columbia, Alberta and Saskatchewan.[§] (6) [§]Note: Increased irrigation in Manitoba resulted in neutral or net increase in GHG emissions	62–82	Cost of infrastructure to source water is not known Net effects of irrigation on N_2O flux from land are not known	Reduced reliance on weather and increased yields but increased costs of production	Increased potential of groundwater contamination. Increased demand on surface and groundwater sources– leading to potential ownership issues and conflict with non-agriculture water users
Improved efficiency of energy and water use for irrigation systems. (6)	220	Cost/benefit ratios of alternative irrigation systems relative to net GHG emissions and farm income required	Conversion to alternative energy sources will require infrastructure costs	
Improved fertilizer use on irrigated lands. (6)				

Increase land area that has improved surface drainage by 40,000 hectare over BAU baseline. (6)	0		Estimated to cost $1,100 per hectare. Could increase yields by 20%	Potential increase in discharge of contaminants from drainage ditches
Increase land area that has subsurface drainage by 631,200– 3,713,400 ha over BAU baseline. (6)	0		Estimated to cost $1,100 per hectare. Could increase yields by 20–50%.	
Increase land area on which a controlled water table is used by 37,200–7,143,000 ha over BAU baseline. (6)	0		Estimated to cost $625 per hectare. Could increase yields by 5–15%.	Potential increase in discharge of contaminants from drainage ditches
Increase land area used for water diversion terraces and grassed waterways by 40,000–80,000 hectare over BAU baseline. (6)	14,100		Loss of income from land taken out of production. Infrastructure costs estimated to range from $5,000/ha for terracing to $10,000/ha for waterways	
Increase land area used for filter strips or sediment basins by 50,000–100,000 hectare over BAU baseline. (6)	4,890		Loss of income from land taken out of production. Infrastructure costs estimated to be $2,000 per hectare	

Increase land area used as farm wetlands (including riparian zones) by 598,000 hectare over BAU baseline. (6)	1,902,400		Loss of income from land taken out of production. Infrastructure costs estimated to be $5,000/ha. Increased pest damage to crops	Wetlands may become major sources of GHG if later drained or dried due to reduced precipitation or increased temperatures (global warming)

TABLE 7. SUMMARY OF GHG MITIGATION TECHNOLOGIES AND STRATEGIES CONSIDERED
MANURE MANAGEMENT

GHG mitigation action/technology	Potential GHG mitigation (Tonne of CO_2 equivalent per year)	Barriers to adoption		
		Technology not ready for commercial use or uncertain mitigation potential	Adverse economic consequences	Adverse environmental or health consequences
Develop a computer based decision support system (i.e. MCLONE) for livestock producers that deals with manure management from the perspective of feed input, manure handling, manure storage, land application, soil incorporation and crop uptake. (12)		Limited data available		
Support research to establish CH_4, CO_2 and N_2O emission rates over the entire duration of manure storage across a wide range of manure types and under our various climatic conditions. (12, 17)		Best management practices promoted have not been assessed relative to GHG emissions		
Taking the necessary steps to ensure that the next farm survey conducted by Census Canada will yield more useful information relative to manure storage and land application for estimations of GHG emission calculations. (17)				
Investigation of GHG emissions from bedded manure packs in animal housing as this practice is being promoted as an environmentally sound manure management system. (17)		Best management practices promoted have not been assessed relative to GHG emissions		

Encourage a change in management practices in solid manure systems for barns that would include reduced use of organic bedding (straw and wood chips), more frequent removal of manure from the barn and maintenance of clean, dry facilities. (3)				
Encourage more intensive pasture management with less overgrazing. (7, 3)				
Housing with liquid manure handling systems should transfer manure to storage frequently, minimize bedding, separate solids from liquids, and maintain clean, dry facilities. (3)				
Manure storage facilities should be designed to increase storage capacity, reduce exposed surface area and reduce storage temperatures of manure. (3)				
Solid storage systems should have a cover (roof), an impermeable base and run-off control. (5)	440,000–1,310,000		Cost of storage cover	
Storage tanks and lagoons should be covered. (5)	560,000–5,510,000		Cost of storage cover	
Concrete pits or tanks under barns should use covers and low temperatures. (3)				
Bottom-loading tanks should be used to reduce aeration. (3)				
Develop and promote the use of acidifiers and nitrification inhibitors for liquid and semi-solid manure storage. (3)				
Encourage controlled composting. (3)			High capital costs	
Encourage anaerobic digestion. (3)			High capital costs	
Separate solids from liquids. (3)			High capital costs	
Build large scale central treatment facilities to service several livestock operations. (3)			High capital costs	Potential energy source

Apply manure on the basis of soil tests. (9, 3)				
Inject or immediately incorporate manure into the soil. Promote band application. (3)			Suited to coarse and medium textured soils only	
Time manure application to match crop needs. Avoid fall application. (5)	500,000		Very narrow window between spring thaw and seeding. Increased problems with soil compaction. Increased manure storage costs	
Alter animal diets to reduce manure Nitrogen excretion. (1, 5)				
Mitigation strategies should focus on GHG mitigation, not nutrient recycling. (12)				

TABLE 8. SUMMARY OF GHG MITIGATION TECHNOLOGIES AND STRATEGIES CONSIDERED
SHELTERBELTS AND FARMYARD TREE PLANTING

GHG mitigation action/technology	Potential GHG mitigation (Tonne of CO_2 equivalent per year)	Barriers to adoption		
		Technology not ready for commercial use or uncertain mitigation potential	Adverse economic consequences	Adverse environmental or health consequences
Encourage the planting of trees for farmyard, field and roadside shelterbelts. (27)	4,458,480		cost of land area taken out of production	

TABLE 9. SUMMARY OF GHG MITIGATION TECHNOLOGIES AND STRATEGIES CONSIDERED BIOFUEL PRODUCTION

GHG mitigation action/technology	Potential GHG mitigation (Tonne of CO_2 equivalent per year)	Barriers to adoption		
		Technology not ready for commercial use or uncertain mitigation potential	Adverse economic consequences	Adverse environmental or health consequences
Conduct full-cycle analysis of modern Canadian ethanol plants, including direct and indirect impact on GHG emissions. (24, 11)				Increased grain product costs to the consumer
Analyze the benefits of regional ethanol plants relative to reduced fuel transportation costs and related GHG emissions. (11)				Increased grain product costs to the consumer
Conduct Delphi-type discussions of future direction and strategies for biofuels. Include energy companies, commercial biofuel companies, farm organizations, renewable energy organizations, researchers, governments, consultants, etc. (24, 11)				Increased grain product costs to the consumer
Harvest biofuels from grasslands with high carbon-fixing plant species such as switch grass. (7)				