Technology and Climate Change

Robert Morrison David Layzell, Ged McLean

1. Introduction

This paper provides a context for assessing the needs for technologies to reduce the concentration of GHG in the atmosphere. It looks at sources, sinks and trends for GHG, in the world at large and in Canada, and at efforts to develop new technologies to achieve the goals of climate change policy.

Technology development is one of many approaches to reducing emissions and absorbing GHG from the atmosphere. Initiatives to address a range of other factors will be needed, including regulation, efficient markets and pricing, emissions trading, education and information, demonstration, voluntary commitments and public involvement. New technologies will be deployed in conjunction with these initiatives, and will be conditional on them for success. Investments in new technologies must be harmonized with the implementation of existing technologies. New technologies will be more successful if they can also achieve non-climate goals, such as better air quality or reduced soil erosion, especially in developing countries, which have more immediate priorities. A broad spectrum of coordinated policies will be required.

Because of the lead times needed to deploy technology and the slow replacement rate of many energy systems, most emission reductions in the timeframe of the 1997 Kyoto Protocol (2008 - 2012) will be achieved by technology that already exists. Beyond Kyoto, more ambitious reduction targets will be required. The IPCC estimates that in order to limit GHG concentrations in the atmosphere to two times the pre-industrial values, emissions from fossil fuels will have to be reduced from the current rate of 6 Gt C per year to about 2 Gt C per year *(IPCC 1995)*. (Additionally about 1.6 Gt C is released from land use changes and deforestation, but a net absorption takes place on land, as discussed below). Kyoto only reduces emissions from the industrial countries by 5%, leaving other countries free to increase. Even the modest Kyoto targets now look difficult to achieve.

Thus the development of new technologies is well matched to the need for further reductions beyond Kyoto, in both scope and timing. In the long term, new technologies will influence very strongly the possibility of achieving acceptable atmospheric concentrations of GHG.

We look here at sectors where new technology may be most needed. In general these will be areas where emissions are large, or growing rapidly, or both. It doesn't follow that a given investment in new technology for these areas will necessarily have a bigger economic or environmental return, but they certainly merit close attention as potential markets.

One approach to emissions reductions is to decouple emissions growth from economic growth, especially in the faster growing sectors. This means ensuring that new equipment, buildings and processes are especially energy and carbon efficient. It may be more effective to design high efficiencies into new systems than to retrofit old ones. This strategy addresses the growth problem directly - it cuts emissions off at the pass.

The Kyoto GHG reduction targets essentially mean reducing the GHG emissions that are projected to occur in the 2010 period under business-as-usual scenarios by an amount equal to the growth between 1990 and 2010 plus the committed reduction from 1990 levels. That is, if a country has committed to reducing emissions by 6% from 1990 levels, and if growth under a business-as-usual scenario for the 1990 to 2010 period is 30%, it must reduce emissions by 28% from the projected business-as-usual 2010 levels. This is a daunting task.

We also review current areas of focus for technology development, to see if there are any obvious gaps and opportunities. Expenditures on R&D are a proxy for meaningful activity in this area, but it will be years before one can assess the returns to R&D investment, in either commercial or emissions terms. R&D is always a risk, but risk management processes can be applied.

Emissions from fossil energy use are the main source of the GHG problem, and CO_2 is the most important GHG, but other GHG, and other factors affecting GHG concentrations, must also be kept in mind. Overall management of the biosphere, and the development of biological and geological sinks to store carbon, can have a significant impact over the longer term.

Without trying to pick winners, we focus in this paper on transport, electricity and biomass as sectors of interest, both because of their potential for contributing to climate change policy goals within Canada, and also because of our own research interests.

2. Factors Affecting GHG Emissions and Concentrations

The amount of GHG emissions from human activity will depend on the combined effect of a series of factors. First is the amount of activity in a particular sector as measured, say, for buildings by square meters of floor space to be heated and cooled, for transport by passenger- or tonne- kilometers, for industry by value added. Each activity can usually be carried out through a variety of sub-activities or modes - travel modes, types of buildings, different industrial processes, etc. The contribution of the different modes, which comprise the structure of the sector, can vary between countries and regions and over time.

The activity measures grow in response to population growth and to the desire for economic improvement. They are also responsive, to varying degrees, to energy prices. They are not easily limited, and governments are reluctant to tamper with them because of the economic and political consequences. The high-growth activities are particularly difficult to contain. This leaves open the option of shifting among sub-activities, say from cars to buses, or from single to multi-unit dwellings, but even here the tendency in many sectors seems to be toward more energy-intensive modes: bigger houses and cars, more urban sprawl. The other factors described below are more amenable to both policy and technology developments.

Second is the energy intensity of the sub-activity: how much energy does it take to heat the space or move the freight, in energy units per unit of activity, Joules per m^2, or per tonne-km. It is the output, the energy services, rather than the energy itself that is the desired product here, and if the service can be obtained more efficiently, so much the better. Striving for better efficiency (and its inverse, lower energy intensity) is clearly a fruitful area for technology development.

However efficiency gains are not necessarily used to reduce emissions. In the vehicle sector, efficiency gains have been used to increase vehicle weight and performance rather than reduce emissions. And the money people save on reducing emissions in one area, say better insulation, they can spend on energy intensive areas like jet vacations.

Third is the carbon intensity of the energy. How much carbon is emitted per unit of energy, in units of tonnes C (or CO_2) per Joule of energy consumed? Reducing the carbon intensity will often involve switching to lower-carbon, renewable carbon or non-carbon fuels, which may require significant technology development.

A fourth factor influencing net emissions will be our ability to capture carbon, and other GHG's such as methane, from processes that would otherwise emit them, and to make use of them or store them in sinks. In many cases this means removing carbon from fossil fuels before they are burned, or CO_2 from combustion flue gases. In other cases it means removing the CO_2 associated with deposits of natural gas. It generally means that one needs access to large, and ideally concentrated, streams of CO_2, so capture opportunities tend to be matched to large point sources

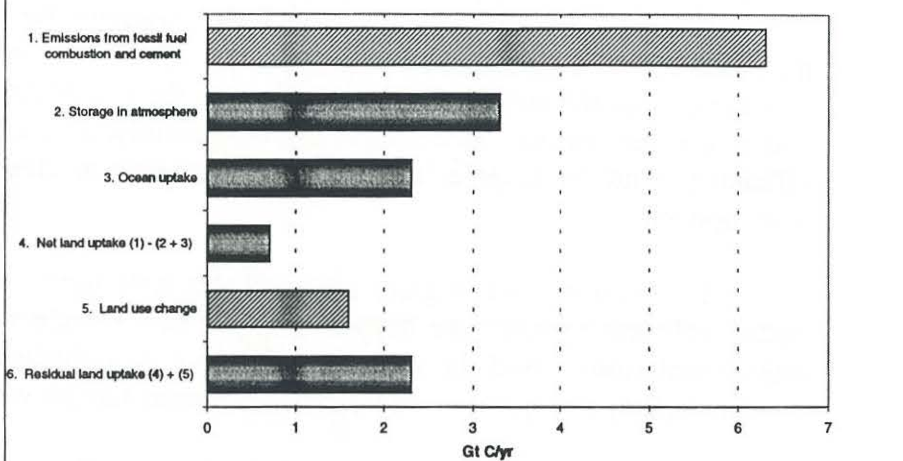
Fifth, through photosynthesis, plants can remove CO_2 directly from the atmosphere at existing or elevated concentrations, and build a carbon stock in the form of energy-rich biomass. By changing the way the biosphere is managed, one can build and preserve biosphere carbon stocks thereby creating a net sink for atmospheric carbon. While many of the management 'technologies' are well known, opportunities exist for new technologies that will enhance the ability to create and preserve biosphere carbon stocks. Equally, if not more important, is the need for tools to verify that these changes in biosphere management or these new technologies do, in fact, result in the quantifiable transfer of greenhouse gases out of the atmosphere.

3. Natural Cycles

Looking at GHG emissions in the context of the natural carbon cycle, the picture presented by the IPCC *(IPCC 2000)* is as follows, in units of Gt C per year:

This deals with CO_2 alone. Other gases would alter the picture somewhat, but since estimates of emissions and removals of other gases are much less reliable, that data is not presented here.

Graph 1 Annual Man-Made GHG Fluxes, 1989-1998
(Billions of Tonnes C per Year)



Source: Summary for Policy Makers, IPCC Special Report on Land Use, Land Use Change and Forestry (LULUCF), IPCC, 2000

About half of the anthropometric CO_2 emissions remain in the atmosphere. The other half is absorbed, mainly in the oceans. Even with man-made emissions of about 1.6 Gt C per year from the forest sector (primarily from burning forests to clear land in the tropics) the overall biomass sector is still a small net sink due to the natural carbon uptake. This suggests that in the absence of the man-made forestry emissions, biomass would be a significant net sink. This sink effect represents the small difference between overall emissions and overall uptake in the natural carbon cycle, which are each about 100 Gt C per year.

4. World Energy Use and GHG Emissions

The International Energy Agency recently published its outlook on global supply and demand for the period 1997 to 2020 (*IEA 2000a*). The report assumed 'business-as-usual', and made a number of predictions, including:

Energy Use. World primary energy use is expected to continue growing over the next few decades by about 2% annually (close to its historic rate), or by about 57% from 1997 to 2020. This is the result of annual population growth of 1%, economic growth of 3%, and an annual decrease of energy intensity by 1%. Carbon emissions are expected to grow slightly faster than energy use, implying that carbon intensity will increase over this period.

Energy Use by Regions. Different regions and sectors evolve at different rates. Primary energy use will grow at 1.7% in the OECD countries, and at 2.7% in the developing countries, which will account for 68% of the increase in world energy use from 1997 to 2020. Transition economies are expected to grow at 2%. This will mean a shift in energy use and emissions. The OECD contribution, currently 54% of primary energy and 51% of CO_2 emissions, will decline to 44% and 40%, respectively, by 2020, whereas the developing country contribution is expected to increase to make up the difference. The transition economies are predicted to remain at about 10% for both primary energy and CO_2 emissions.

Energy Use by Sources. In terms of sources, oil is expected to retain it's 40% market share, reflecting its importance in transport. International trade in oil and gas are expected to increase sharply while the share of natural gas in the energy market increases from 22% to 26% by 2020. Coal is expected to decline from 26% to 24% of global energy supply, although its consumption is predicted to increase significantly in absolute terms. India and China are expected to account for two-thirds of the increase in coal use, mainly for electricity. The overall share of fossil fuels increases slightly to about 90% of the global energy supply.

Of the remaining 10%, nuclear is predicted to decline slightly to 5% while hydro continues at about 2% (hydro's share of electricity production is similar to nuclear's but its share of primary energy is less because it is rated at the equivalent of 100 % conversion efficiency, whereas nuclear is at 33%). Non-hydro renewables will grow rapidly, at about 2.8% annually, but will represent only about 3% of the market by 2020. Biomass consumption for energy use (largely in the developing countries at the present time) is expected to decline in favour of commercial fuels, while becoming more commercial itself.

Energy Use and Emissions by Sector The most rapidly growing sectors are expected to be electricity at 2.7% and transport at 2.4%, increasing their shares of the market from 17% to 20% by 2020, and from 28% to 31%, respectively. The bulk of the increase will be in developing countries. End-use sectors other than transport grow at 1.8%.

A recent model of sectoral energy growth suggests that industrial energy use peaks in countries having a GDP of about $10 000 per capita and declines slowly above that *(Medlock and Soligo 2001).* Residential and commercial use overtakes industry in countries with GDPs between $10 000 and $25 000 per capita, the level of the richest countries today. The model predicts that transportation will continue to grow, becoming the biggest sectoral user of energy in countries with GDP per capita levels above $25 000.

A study of sectoral GHG emissions among 14 OECD countries (*Schipper et al 2001)* indicates that activity levels are likely to be the main source of differences in emissions, followed by utility carbon intensity and energy intensities. Activity levels are related to GDP, but at the same level of GDP, activity levels in different sectors can vary significantly among countries. The US has the highest per capita emissions, due to a combination of high activity in transport, residences and services (e.g. floor space), high energy intensity in industry, transport and appliances, and high carbon intensity in the electrical utility sector. Canada has similar characteristics, except that its utility carbon intensity is low, and its climate is colder. Japan has lower emissions due to low activity in transport services, and low energy intensities for industry and residences, but its absence of natural gas consumption in the fuel mix increases emissions to some degree.

Activity levels, as noted above, are difficult targets to address for both policies and technologies. Energy intensities, via efficiency, and carbon intensity, via fuel switching, are more amenable to intervention, as are the management of biomass and the use of sinks.

Among sectors, energy demand growth in transport and electricity is difficult to tackle with policy and pricing initiatives. The services these sectors provide are seen as essential to the economy and to modernization programmes. Large infrastructures are in place. The cost of energy is generally a small part of the overall cost of these services, and the price elasticity is low in the short term. Competitive alternatives to oil in transport will not be easy to implement widely or rapidly. We'll hear more about the longer-term possibilities later. For electricity there is a range of possibilities for using zero carbon fuels, such as hydro, other renewables and nuclear, or less carbon intensive fossil fuels, notably natural gas. In both sectors, efficiency improvements all along the fuel chain are a major source of hope for reducing emissions.

Emissions and Potential Reductions. For the world, the 1990 emissions and estimates of the reduction potential for different sectors are given by the IPCC *(IPCC 2001).* The units are tonnes of carbon equivalent, or tonnes Ceq (multiply by 3.67 for CO_2 eq) per year.

Buildings presumably refer to what other classification schemes call Residential and Commercial. Energy supply and conversion is included in the other sectors for historic emissions. Future reductions in this category are for electricity only.

Table 1 World GHG Emissions and Reduction Potential (Millions of Tonnes of C Equivalent per Year)

Sector	Historic Emissions 1990	Emission Growth 1990-95 (%)	Reduction Potential 2010	Reduction Potential 2020
Buildings	1650	1	700-750	1000 - 1100
Transport	1080	2.4	100 - 300	300 - 700
Industry	2300	0.4		
energy			300 - 500	700 - 900
material			200	600
Industry - non CO_2	170		100	100
Agric CO_2	210	n/a		
non-CO_2	1250 - 2800	n/a	150 - 300	350 - 700
Waste	240		200	200
CFC	0	1	100	na
Energy supply, conversion	-1620	1.5	50 - 150	350 - 700
Total	6900 - 8400		1900 - 2600	3600 - 5050

Source: Summary for Policy Makers of the Mitigation Report, IPCC, Third Assessment Report, WGIII, Accra, February-March 2001

There are great uncertainties in all sectors about the potential for reduction, and the costs, so the numbers for potential reductions should be taken as indicative only. However, the general conclusion is that existing technologies could allow the Kyoto targets to be reached if they could be fully deployed, a prospect that at present seems unlikely.

According to the IPCC, the most promising areas for global GHG reductions in absolute terms are buildings and energy efficiency in industry, and most initiatives in these areas should result in net negative costs. They may be undertaken independently of climate change goals, on a "no regrets" basis. Most of the potential for efficiency gains in buildings are in the industrialized countries. The next most promising in absolute reduction terms are material efficiency in industry, along with agriculture, transport, and energy supply/conversion, with a wide range of costs. Transport and industry can achieve savings up to about 50% of the 1990 emission levels, but transport is growing very quickly.

The IPCC suggests that about half of these reductions can be obtained at negative cost, that is they should provide net economic benefits. Most of the other half should be available at net costs up to $100 per tonne Ceq, or about $27 per tonne CO_2 *(IPCC 2001a, p. 4)*, although some options range up to net costs of $300 per tonne Ceq, or $80 per tonne CO_2 *(IPPC 2001b, p. 28 and Table TS.1)*. Taking 2 000 Mt Ceq in 2020 as half of the total reductions that might be achieved, the cost at $100 per tonne Ceq would be about $200 billion per year.

The IPCC also sees carbon capture and storage, and biomass management, as important factors. The Second Assessment Report estimated that about 60 to 87 Gt C could be sequestered in forests by 2050, and another 23 to 44 Gt C in agricultural soils. Costs range up to $20 per tonne C in some tropical countries and up to $100 per tonne C in non-tropical countries *(IPCC 2001b, p. 43)*

A recent IEA study *(IEA 2000b)* also looks at technologies to reduce GHG. With R&D funds scarce, governments have a key role in stimulating a longer term approach: reducing barriers to acceptance, developing efficient markets and correct price signals, leading by example, covering some of the risks, providing information, accelerating the availability of new technologies and supporting their uptake. Several technologies have taken off faster than anticipated a decade ago, and show signs of further promise: wind turbines, community energy, gas-fired power plants, hybrid gasoline-electric vehicles, windows and lighting, and rooftop photovoltaics. The IEA study outlines, by way of example, some technologies that would benefit from further investment in R&D. A number of these would lower GHG emissions in their subsector by 20% or more: industrial processes and separation (membranes, etc.), electric-hybrid vehicles, fuel cell vehicles, biofuels, gas-fired power plants (especially if replacing coal-fired plants – this would be enough to reach Kyoto targets for many countries), nuclear energy, and stationary fuel cells. In many cases the technology exists, but R&D can help to lower costs in order to achieve commercial deployment.

In conclusion, while GHG emissions come from a very broad range of human activities, it seems that major sources of growth in emissions will be the developing countries, and that transport and electricity will be the high-growth sectors both there and worldwide. The growth of coal-fired power plants in developing countries is itself a major factor, as they are expected to cause about one-third of the global growth in emissions over the period to 2020.

5. CANADA's GHG Emissions

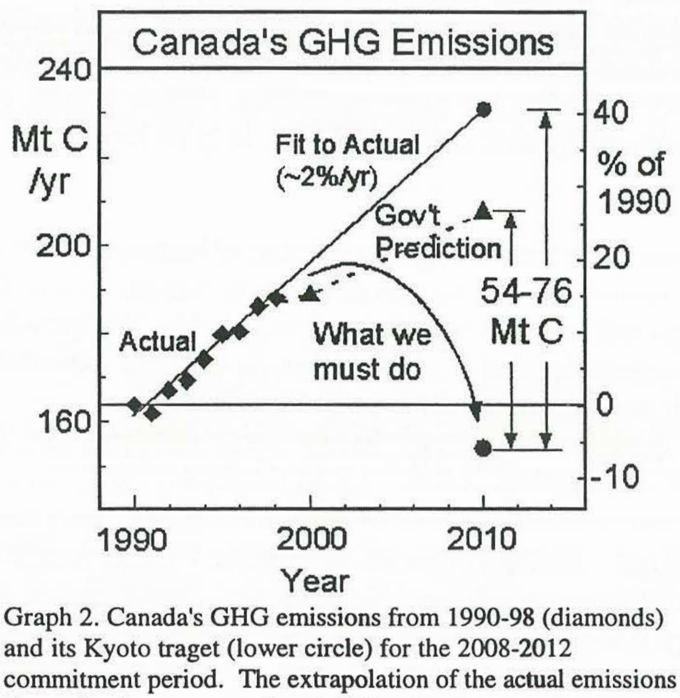
Past, Present and Future Emissions. Although Canada represents a small fraction of overall world GHG emissions, our GHG emissions are high in per capita terms. The *Implementation Strategy (Government of Canada 2000)* explains this high use as the result of weather extremes, large land mass, high population growth rate, and resource-based, energy-intensive, export-oriented industries. It would be interesting to have a measure of the contribution of these factors, as well as that of a suburban lifestyle that uses land and buildings extensively, with its attendant needs for transport, building space, etc.

In 1997, total GHG emissions for Canada were 682 million tonnes of GHG, in CO_2 equivalent. CO_2 represented 76%, or 518 million tonnes *(NCCP 1999).* Energy represents about 79% of the total. Agriculture and forestry contribute about 10% of the 20% non- CO_2, mainly methane and N_2O, and almost none of the CO_2. The other 10% of non- CO_2 comes mainly as methane from the fossil fuel industries and from landfill, and as N_2O from specific industrial processes.

For consistency with the IPCC figures, we convert Canadian GHG numbers into tonnes of carbon or carbon equivalent, t C or t Ceq. Total GHG emissions from Canada in 1997 were thus 186 Mt Ceq, up from 164 Mt Ceq in 1990. This represents an increase of 13%, due to growth in economic activity, population, energy exports and consumption. Over 50% of Canada's oil and gas is exported, and this trend will continue. Energy intensity has improved in the overall economy, but economic growth has outstripped efficiency gains by a factor of two (better than the world at large, where the ratio is three to one).

Total GHG emissions for Canada in 2010 are conservatively projected to be 27 per cent above 1990 levels, at 208 Mt Ceq, , in a business-as-usual scenario. GHG emissions in 1990 were 164 Mt Ceq, the Kyoto target is 154 Mt Ceq, so the gap is 55 Mt Ceq., or 33 per cent of the 1990 level.

In fact, if a linear regression is fit to the reported emissions from 1990 to 1998, an extrapolation of this line would predict that 2010 emissions would be over 230 Mt C per year, or about 76 MtC/year over the Kyoto target (Graph 2). Therefore, if the 1990's are indicative of 'business as usual' conditions, Canada's emissions gap would be equivalent to +46% of the nation's 1990s emissions.



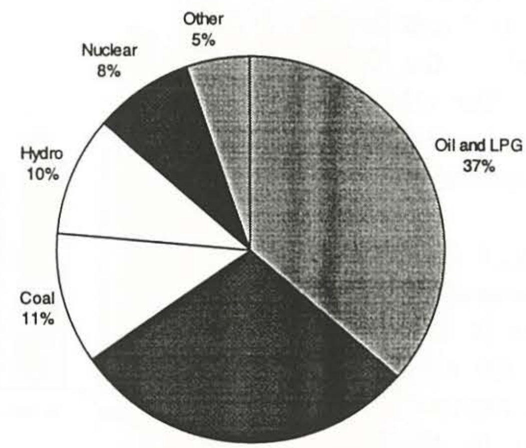
Graph 2. Canada's GHG emissions from 1990-98 (diamonds) and its Kyoto traget (lower circle) for the 2008-2012 commitment period. The extrapolation of the actual emissions fives a business-as-usual projecdtion (upper circle) that is higher thatn the fedeal government prediction (triangles).

Energy Use by Regions. Alberta and Ontario are by far the biggest GHG emitters, each with one-third of Canada's total emissions. Emissions growth is fastest in Alberta, mainly through oil and gas production, and in BC, mainly through transportation. Generally, provinces involved in fossil fuel production will see more rapid increases in GHG emissions over the next few decades.

Energy Use by Source. The ***Strategy*** shows energy demand in Canada by fuel type for 1997:

Canada's fuel mix differs from the world average in that oil's share is slightly lower, coal is much lower, and natural gas and hydro are significantly higher. Nuclear's share in Canada is slightly higher than the world average, but lower than the average for the OECD, where it provided 29% of energy supply for electricity in 1995.

Graph 3 Energy Demand in Canada by Fuel Type, 1997



Source: Canada's National Climate Change Process, Canada's National Implementation Strategy on Climate Change, October

In terms of GHG emissions by fuel type, oil and gas are by far the main sources in Canada. In projections, natural gas almost catches up to oil by 2020. Growth in oil emissions is mainly due to transport, and in natural gas to electricity generation, especially after 2010. Coal's share of emissions is declining, due to the gradual replacement of its share in electricity generation by gas, although it continues to grow in absolute terms.

Canada's fuel mix, with a high proportion of low- or non-carbon fuels, decreases its emissions relative to other industrialized countries. While Canada can still make gains by changing its fuel mix, our high emissions are due to other factors.

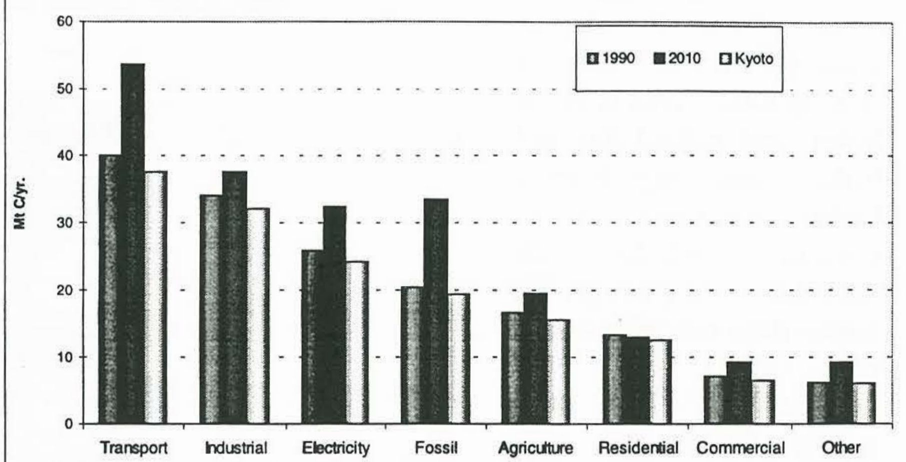
Energy Use and Emissions by Sector. GHG emissions by sector for 1990 and projected for 2010 are shown in Graph 3, along with assumed Kyoto targets for sectors, *(NCCP 1999).*

For illustrative purposes, the Kyoto targets shown for each sector are simply the 1990 levels minus the 6% for Canada's overall commitment. Of course different targets may be assigned to different sectors.

Transport and fossil fuel production are the biggest absolute contributors to GHG emissions growth, because they are growing most rapidly in absolute terms, and in percentage terms also. Emissions from fossil fuel production will be up 64% from 1990 to 2010, due in part to oil sands development, and those from transport up will be up 34%. Transportation is already up 17% from 1990 to 1997. Gains in vehicle efficiency have been used to increase vehicle weight and performance rather than reduce fuel consumption. Truck traffic is up sharply, in part due to increased international trade.

As in other OECD countries, 80 - 90% of energy use in transport is by automobiles and light personal trucks. Canada's large distances increase the emissions from transport, notably for air travel and freight, compared to the OECD average. The other large OECD countries, the US and Australia have similar patterns. However, it is interesting that average car trip distances in Europe and the US are about equal, but the number of trips per day in the US is double that in Europe *(Schipper et al 2001).*

Graph 4 Canadian Emissions, Growth and Assumed Kyoto Targets (Million Tonnes C per Year)



Source: Canada's Emissions Outlook, AN Update, NRCan, December 1999

Electricity and industry are next in absolute size of emission growth, partly due to the large absolute size of the sector emissions to begin with, partly due to growth, especially for electricity.

Agriculture is fairly large in emission terms, although growing slowly. This category includes forestry, although the majority of the emissions are associated with CH_4 and N_2O emissions from fertilizer use in cropping systems and from farm animals and their manure. Interestingly, the residential sector is shrinking on its own, despite the growth in stock, presumably because of buildings standards, and perhaps also because consumers are, in fact, sensitive to price signals and incentives, although seemingly more so in this instance than for personal transport.

The commercial sector's contribution is small. The large size of its gap in percentage terms is due to the rapid projected growth of the service sector, with its need for more electricity-intensive office equipment and for floor space.

Individuals are directly responsible for about 28% of Canada's GHG emissions through transportation, home heating, and electricity *(NCCP 2000a).* Production of consumer goods is not included in this measure. If one normalizes energy use in buildings by both floor space and degree-days, Canada has relatively low energy intensity, because insulating our buildings is a good investment. However, Canada's cold climate (six times more degree days than Australia, where degree days are the number of days where the temperature is less than 18 degrees Celsius, multiplied by the difference between the temperature and 18 degrees Celsius) and the relatively large amount of floor space per capita drive up emissions for buildings *(Schipper 2001).*

Note that the emissions from Canada by sector are different from those in the world as a whole. Industry and buildings represent a much larger share of emissions for the world, while transportation is clearly more developed in Canada.

This brief survey suggests that energy-using activity levels in Canada are likely to increase. Reductions in emissions must be sought through greater efficiencies, changes in fuel mix, new approaches to energy use and energy systems, and carbon capture and sequestration. Key sectors, because of their size and likely growth, will be transport, fossil fuel production and electricity.

Also, given Canada's vast land area and the relatively large size of its agriculture and forestry sectors, biomass has a unique contribution to make as both a source of renewable energy and a sink for emissions. However, a greater reliance on agriculture for the production of bio-based fuels and other products could increase the already significant GHG emissions associated with this sector. New technologies are required to enhance agricultural production while reducing GHG emissions.

6. Technologies to Reduce Emissions or Enhance Sequestration, and Key Sectors

The Options Exercise and the Technology Table. Canada's national Options Tables Exercise in 1999-2000 looked at GHG technologies for both the near term and the longer term, through a series of consultative "tables". Most of the tables looked at existing technologies that could be implemented in the Kyoto timeframe, from the perspective of the technology users. The Technology Table *(IPCC 2000b)* examined technologies that might be applied beyond the Kyoto timeframe, from the perspective of the technology supply community.

The Technology Table stressed that a sustained commitment to technology development should be made as soon as possible. It outlined the required funding, an annual amount increasing from $100 million to over $500 million over five years, mainly in demonstration, at $300 million/yr and in technology development, at $200 million/yr. This would help meet the targets for Kyoto and beyond, reap ancillary benefits, and position Canadian companies for international competition in GHG technology.

The Table proposed options in four areas pertaining to Canada's innovation system for GHG technologies: knowledge infrastructure, including human resources, demonstration and commercialization, the export business climate, and linkages and partnerships. It stressed the need to find the right regional balance for actions across Canada.

The Table discussed 25 groups of promising technologies for GHG mitigation in six broad categories to illustrate some of the possibilities, not to select a definitive set for investment. In so doing, they looked for technology areas where there was an emerging Canadian capability, and ideally both a Canadian and an international need. The categories were:

- Fossil fuel supply
- Energy production, mainly electricity and biomass
- Energy end-use, mainly fuel cells, buildings and transportation
- CO_2 management, notably geological sinks
- Non-energy GHG emissions - cement, agriculture and wastes
- Enabling or cross-cutting technologies, including hydrogen.

In all, the Table identified about 1300 specific technologies for consideration. They also carried out some detailed studies of countries and sectors where Canada's would find good export markets for its GHG technologies. Proposed funding for most of the 25 illustrative technologies was in the range of $5 - 30 million per year.

In the 25 groups, there is some consideration of the likely cost range, and also of the likely market. However, it is difficult to do this systematically across activities that are so different in nature, in potential, and in stages of development, and of course with longer term R&D there are many uncertainties. What one would want, ideally, is a chart that shows for each technology the potential for emissions reduction in different timeframes, and the cost per tonne of carbon saved. What one gets is a fairly broad range of both costs and reduction potential, as with the IPCC and IEA studies. Decisions must inevitably be made under conditions of uncertainty. R&D can help to reduce that uncertainty.

Canada's Action Plan 2000. This Plan *(Government of Canada 2000),* draws on the Options Process. It involves new expenditures of $500 million plus $625 million already announced, to be spent over the next 5 years, building on $850 million that the government of Canada has already spent. The total reduction from the initiatives outlined in the *Action Plan* is expected to be one-third of the Kyoto Gap. The remaining two-thirds will be achieved by measures yet-to-be-announced.

Action Plan 2000 targets key sectors that contribute 90% of Canada's emissions: transportation, energy (oil and gas, and electricity), industry, buildings, forestry and agriculture, international, and future solutions.

Table 2 shows some aspects of the Plan. The first column *(NCCP 1999)* shows the percentage contribution of each sector to Canada's total GHG emissions in 1998. The second, (*Action Plan, Chart, p.4)*, shows the percentage contribution of each sector to the total reductions under the Plan. The third *(NCCP 1999)*, shows the expected growth from 1990 to 2110 under a business-as-usual scenario.

A useful comparison can be made between the first and second columns. Transportation, electricity, and fossil fuels, fast-growing sectors, make contributions to reductions that are much smaller than their share of total emissions. Agriculture and forestry make larger contributions than their share, through biomass management and sinks. International mechanisms, through which Canada can obtain emission reduction credits for projects undertaken in other countries, are expected to pick up 25% of the total. Thus almost half the reductions in the Plan are due to international mechanisms or sinks. Comparison of the second column with the third is also interesting. The higher growth areas are not the strongest candidates for reductions, so that their growth is less restrained. This is especially significant in light of our belief, noted above, that emissions growth under the business-as-usual scenario is likely to be much higher than the government's projection.

Table 2 GHG Emission in 1998, Reductions and Growth by Sector

Sector	% of total in 1998	% of reduction under Plan by 2008-2012	% growth to 2010 under business-as-usual
Transportation	25	10	34
Electricity	17	20 inc.oil & gas	25
Oil and Gas	18		65
Industry	15	15	10
Buildings	10	10	9
Ag and Forestry	10	20	18
Other	5		48
International		25	
Total	100	100	27

Source: Canada's Emissions Outlook: An Update, NRCan, December 1999, and Government of Canada Action Plan 2000 on Climate Change

Proposed Actions in Action Plan 2000 by Sector. Given the time frames and the time lags to deploy technology on a large scale, almost all the reductions to 2010 will depend on technology that is ready or almost ready for deployment today. Technologies that still require development, and that could be deployed after 2010, are indicated below under technology as a sector in its own right. The Plan's proposed areas of focus are as follows:

- *Transportation:* Fuel efficiency, new fuels, fuel cells, efficient freight, urban transportation.

- *Energy (Fossil fuel production).* CO_2 capture and storage, efficiency, (building on the Weyburn experiment with CO_2 disposal, and on coal bed methane, and working with the Regina centre which coordinates Weyburn and encourages R&D.)

- *Electricity.* Reduce barriers to trade (to allow more use of lower carbon and renewable sources) , develop lower carbon sources, e.g. renewables, and CO_2 capture and storage. Purchase and subsidize renewables,

- *Industry.* CIPEC, reporting, benchmarking, efficiency audits, incentive to exceed code requirements by 25%. Renewables (biomass, solar hot water, ground-source heating), metal recycling, concrete roads.

- *Buildings.* Near term, retrofit. Long term, build to higher efficiency. Standards for appliances. Upgrade the Model Energy Code.

- *Government Ops.* Try to reduce by 31%. Create the market. Retrofits, fuel switching, renewables.

Agriculture and Forestry. Alter biosphere management strategies and develop new technologies to reduce GHG emissions associated with agriculture, and enhance biosphere carbon stocks. Also, develop bioprocessing technologies to use biomass as a source of renewable energy, chemicals and materials. .

- *International.* Office for Clean Development Mechanism and Joint Implementation set up within DFAIT.

- *Technology (Future)* - R&D: find new ideas through discovery competitions, develop through basic university research and support their advancement. Collaborate: develop networks and technology road-maps, national forum; Market Technology: support business environment for innovation, showcase Canadian technology to domestic and international markets.

7. Specific Sectors

A. Electricity

Current Situation Decisions on developing new technology to achieve climate change goals for the electricity sector will depend on the sector's characteristics. The share of Canada's electricity that comes from fossil fuels is relatively low, about 27% in the year 2000 *(Statscan 2001)*, due to the high share of hydro (61%), but also to the nuclear share, currently about 12%. Fossil fuels contribute about 27%. The bulk of this is from coal. About 90% of the coal consumed in Canada is used to generate electricity. Half of this is consumed in Alberta, and a quarter in Ontario.

As hydro and nuclear are effectively GHG emission-free (some hydro projects release methane from flooded reservoirs, but the overall effect is believed to be fairly small), the share of Canada's total GHG emissions that comes from the electricity sector is also relatively low - about 17%, versus 35% for the OECD countries on average, 34% for the world. Countries such as France, Switzerland, and Sweden also have low emissions from electricity due to various combinations of hydro and nuclear sources.

Nonetheless, in absolute terms, per capita GHG emissions from Canada's electricity sector are high because of our large per capita consumption of electricity, the highest in the world except for Norway and Iceland, which have extensive hydro resources and small populations. Canada's per capita electricity consumption is about 20% higher than the US, and double that of Germany, Japan, the UK or France.

In 1994, the breakdown of electricity production by source was 61% hydro, 19% nuclear and 20% fossil, mainly coal. Since then, the nuclear share of Canada's electricity has fallen, and the fossil share has increased, due to the shutdown of eight Candu nuclear units in Ontario in 1997, and the construction of a number of natural gas plants.

Fuel Mix The GHG emissions from a 1000 MW coal plant operating at 80% capacity factor (e.g. at 100% of its output for 80% of the time) will be about 5.6 Mt of CO2 per year, or 1.5 Mt C per year, and about half that from a natural gas plant. These are the target amounts that can be reduced or eliminated by using lower-carbon or non-carbon sources. They are significant in terms of meeting Canada's Kyoto targets.

The most effective near-term route to emissions reduction in the electricity sector would be a shift in the fuel mix as new plants are brought on line to replace existing capacity or to meet new demand growth. Since power plants involve large capital investments and generally operate for 30 years or more, decisions on the type of technology and fuel for each new plant have long-lasting implications. Each new plant is a major opportunity to influence the future fuel mix. In turn, the fuel mix of Canada's electricity sector will largely determine utility carbon intensity, and will have a large impact on GHG emissions from this sector. However, plants built to supply new demand growth are likely to be fairly rare in Canada in the next decade due to a combination of slow demand growth and, in some areas, excess capacity. A current estimate of electricity demand growth over the next few decades is about 1.7 per cent *(NRCan 2000).*

The current trend is to favour natural gas plants for new and replacement capacity. To the extent that they displace or replace coal plants, they would reduce emissions. To the extent that they replace or displace nuclear, hydro, and other renewables, they would increase emissions.

Another immediate opportunity for a shift in fuel mix in the electricity sector would be the re-start of the nuclear units in Ontario. Four of the nuclear units at Pickering are being restarted over the next year or two, and two at Bruce are expected to follow shortly thereafter. If these plants, representing about 3700 Mwe of generating capacity, return to service and run at reasonable capacity factors, fossil and nuclear electricity will again achieve a better balance.

Further development of Canada's hydro resources could contribute to the reduction of emissions in neighbouring provinces and in the US. In some cases new transmission capacity may be required. Investments in R&D on hydro development, and its environmental impacts, and on the stability and efficiency of transmission systems, can further enhance the effectiveness of Canada's main source of electricity.

Increased interprovincial trade could displace higher cost plants with lower cost ones, probably increasing the use of hydro power in Canada. Higher electricity exports to the US are also a possibility *(Goodale 2001)*, including those from plants dedicated for this purpose. Exports would favour hydro plants and also some nuclear plants, as both compete in the market on the basis of their fuel and operating costs, which are very low. Since US fossil plants contribute to air pollution in Canada, exports of GHG-emission-free Canadian power would have the ancillary benefit of better air quality for both countries.

In the medium term, the replacement of coal-fired plants in several provinces with lower- or non-carbon alternatives, or the development of sinks that can absorb the carbon from coal plants, could make a significant contribution. Coal reserves are abundant and low-cost. The normal remaining life for existing coal plants in Canada varies from 5 to 30 years *(NPCC 2000d)*. New plants are more readily equipped for capture and storage than existing ones.

Efficiency While the fuel mix can be shifted with existing technologies, the development of more efficient, lower-cost, lower-carbon alternatives is needed to enhance the reduction potential over the medium and longer term. Improvement in end-use efficiencies, such as industrial processes, motors, appliances, lighting, sensors and controls, will also be very important, but we do not have space to address them here. Of course, improvements in the efficiencies of fossil-fired plants would be welcome in their own right.

The most pressing need is R&D to reduce the costs of lower-carbon alternatives, including the costs of carbon capture and storage, in order to help them compete in an increasingly integrated and competitive electricity market.

Greater use of combined heat and power can contribute to greater efficiencies, where thermal and electrical loads can be matched. The development of other renewables, notably wind power, can contribute in some regions, although the contribution is expected to be small in overall terms. Intermittent renewables will require back-up capacity. Biomass can contribute to local economic development, where a reliable supply can be maintained. For nuclear energy, the challenge is to lower the capital costs, while maintaining high safety and reliability standards, and take full advantage of developments in instrumentation and control.

The Electricity Options Table *(NPCC 2000d)* concluded that the most important single step to reduce emissions in the electricity sector would be the establishment of a value for the carbon in carbon emissions. The IEA has drawn similar conclusions *(IEA 2000)*. The Table cited three related policy issues that must be resolved: the impact on competitiveness, the allocation of the burden among regions and sectors (not easy given the distribution of fossil fuel use for electricity in Canada), and access to international mechanisms.

Such a move to a real cost for carbon, whether through taxes or emission trading, would internalize the costs of climate change. It would favour low and non-carbon renewables, and help to create a least-cost route to reducing emissions. And it would allow a clearer picture for investors deciding on which technologies are likely to achieve the best return in the medium term.

B. Transportation

Emissions from transportation are currently at 40 Mt C (148 Mt CO_2) equivalent and are expected to rise to 53 Mt by 2010 under a 'business as usual' scenario. In order to achieve the Kyoto targets, transportation sector emissions will need to be reduced by 28% to achieve pre-1990 levels. The transportation sector is the largest contributor to GHG emissions. However the sector itself represents a diverse array of technologies and practices, from individual use of automobiles to the commercial airline industry. As such, no single prescription for achieving Kyoto targets is possible. To illustrate this point, 44% of transportation emissions are from personal light duty vehicles, with the remaining emissions from commercial transportation including trucking, rail, air and marine vehicles.

Options for GHG emission reduction in transportation are many. Transport Canada conducted an 'Options Table' to consider viable scenario's for GHG reduction in 1999 *(Transport Canada 1999)*, and other jurisdictions have engaged in similar activities *(IWG 2000)*. These generally agree on defining four approaches to GHG reduction in transportation:

1. Policy and encouragement of voluntary measures to make more efficient use of existing transportation technologies
2. Economic mechanisms (taxes, feebates etc.) to encourage efficiency and the transition to lower GHG technologies and practices
3. New incremental technology to improve the efficiency of transportation technology.
4. Complete redesign of transportation technology with new energy technologies based on zero carbon content (zero carbon energy sources).

While there is an obvious emphasis on the technology of energy supply, storage and conversion for transportation, it should be understood that all four avenues for mitigation rely extensively on new technological developments that were not available ten years ago. In particular, many plans for enforcing policy measures or deriving enhanced efficiency through better planning are dependent upon the widespread availability of information technology.

Transportation services are an integral part of the fabric of Canadian society. The coupling of transportation with both cultural practice and economic activity make the true impacts and costs of any mitigation strategy almost impossible to quantify. Furthermore, the global nature of transportation technology makes major technological change within Canada alone a virtual impossibility. The cost of developing a 'Canadian only' technology solution is simply too high. Rather, the global need for transportation technologies that do not emit GHG's represents a huge opportunity for Canadian Technology to take the world stage, and Canada is recognized as a leader in the field of zero emission energy technologies.

Any discussion of modifications to transportation technology must also note the coupling between GHG emissions and other emissions that contribute to local air quality, particularly in urban centers. Given the profile of health care on the current political agenda, local air quality issues may present a more compelling and more urgent need which Canadians will appreciate and respond to. While in most cases reduction of smog gas emissions accompanies reduction in GHG emissions, this in not always the case. It is possible we will face the undesirable position of two environmental concerns competing with each other for different policy and technology alternatives.

The Kyoto accord outlines a schedule for emissions reductions in the 2010 – 2020 timeframe. There is little chance of introducing widespread zero emission vehicle technology within the next ten years, particularly when much of that technology is still in the development stage and there is no legislation to force its adoption. Zero emission vehicles coupled with sustainable energy sources present a laudable goal for technology development, but free market decisions to replace existing technology are influenced by many factors other than environmental correctness. A personal decision to replace a car or a business decision to upgrade a fleet of vehicles must also consider cost, quality of service and availability – all areas where new technologies have either inferior performance compared to existing alternatives or are simply unproven. Who will reward the pioneers?

Efficiency

Efficiency improvements in our existing transportation technologies are often cited as a vital mechanism for reducing GHG emissions. Transportation technology has been steadily increasing efficiency at about 0.75%/yr for at least the past ten years. However, the push for efficiency is also coupled with demand for increased quality of service from vehicle drivers. In the light-duty vehicle sector these efficiency improvements are translated into increased power and expanded 'hotel loads' on vehicles. In commercial transport the drive for efficiency is to reduce costs and increase the gross carrying capacity of the combined transportation fleet (fuel economy has remained relatively constant, but the cars are getting larger [cite]). Improving technical efficiency alone will not stem the growth in transportation utilization. During the period between 1990 and 2010 the number kilometers per year for the combined fleet is expected to increase from 265 billion Kilometers to over 400 billion Kilometers. Doubling the efficiency of conventional vehicles is simply not possible.

However, quite apart from technical efficiency, it is nonetheless possible to improve the efficiency of the utilization of the overall vehicle fleet and by so doing achieve significant GHG reductions. Policies that encourage high occupancy vehicles, scheduling programs to plan efficient vehicle routings, modifications to road surfaces to reduce losses are a few examples of myriad policy options which, if adopted, have potential to reduce GHG emissions. These measures are attractive in that they do not demand significant technology change, can be applied to the existing vehicle fleet and generally offer a zero cost or very low cost means of achieving emission reduction. However, it is difficult to guarantee the adoption of voluntary policies and the potential unintentional impact of such practices is also difficult to assess.

The transportation table estimates that feasible measures to improve efficiency, not including price mechanisms or other direct economic tools, could produce a 10 Mt reduction in emissions by 2010. The cost of these measures is negligible.

Incremental Technological Change

While there is no question of the need to modify transportation utilization patterns through policy and education, it remains a necessity to deploy new technologies that produce lower emissions while delivering an equivalent service. Our current transportation technology is based entirely on the coupling of hydrocarbon fuels with internal combustion engines to produce work. Near term technology alternatives for each of these two components are emerging.

Fuel substitution with lower hydrocarbon fuels provides one avenue for transition toward a lower emission technology. Starting with gasoline-ethanol blends that run in conventional engines and moving toward progressively lower hydrocarbon liquids produced from natural gas (methanol) and biomass (ethanol) sources, there is the possibility of an incremental movement toward lower hydrocarbon fuels. In the case of ethanol production, the magnitude of the greenhouse gas benefit is largely dependent upon the nature of the biomass feedstock that is used to produce the ethanol. Feedstocks like starch from energy-intensive, nutrient demanding crops such as corn produce a fuel with net GHG emissions that are only marginally better than gasoline. However, production of ethanol from agricultural or forest residues (lignocellulosic biomass) or from biomass grown with minimal inputs may have a much better GHG benefit. The challenge is that conversion of lignocellulosic feedstocks to ethanol requires the use of emerging technologies that have yet to be implemented on the large scales (and economics) needed to serve the transportation sector.

Therefore, at the present time and state of technology, there are difficulties with fuel substitution as a strategy for GHG reductions in the transportation sector. The net emission reduction achievable with fuel substitution is in most cases modest (see Graph 1), so even complete substitution of existing fuel with one of these low emission alternatives would probably not produce the necessary level of emission reductions required to achieve the Kyoto targets. Furthermore, although most of these fuel substitutes are liquid fuels, it does not follow that they can be easily integrated into the existing fuel distribution infrastructure without major new improvements. Gaseous fuels present an even larger challenge, particularly in the off-road industrial transportation sector. Some Canadian technologies for fuel substitution stand out. In particular, Westport Innovations have developed a natural gas injector technology for use with Diesel engines and are focused on deploying this in new diesel engine applications. This is a world-leading technology that can be extended to allow diesel engines to operate directly on Hydrogen as the infrastructure for that fuel develops.

Difficulties with scenarios for fuel substitution include estimating the cost of infrastructure replacement, the identification of policy and market mechanisms to persuade consumers to switch to new fuel technologies (fuels beyond very light gasoline blends require engine modifications) and the possible land use implications of some options (in particular ethanol from 'fuel crops' such as corn). However, the Transportation Table was able to develop a package of scenarios around fuel substitution that lead to a predicted 0.5 Mt reduction (only 4% of required reduction to achieve Kyoto targets) at a cost of between $25 and $50 per tonne.

An alternative to fuel substitution is to replace the existing combustion-only vehicle drivetrain with a hybrid gasoline-electric system. Using such approaches, the fuel infrastructure does not change, but the vehicles are able to achieve dramatic performance improvements through the combined use of short-term energy storage in electro-chemical form and the efficient operation of small internal combustion engines. In the 2000 Tour du Sol, which showcases new vehicle technologies, hybrid electric vehicles achieved 55% GHG emission reduction compared to conventional vehicles over a 500 km test in identical conditions. This has led some researchers to conclude that the Kyoto commitment could be met by a transition to such hybrid vehicle technology (*Patterson 1999, Patterson 2000).*

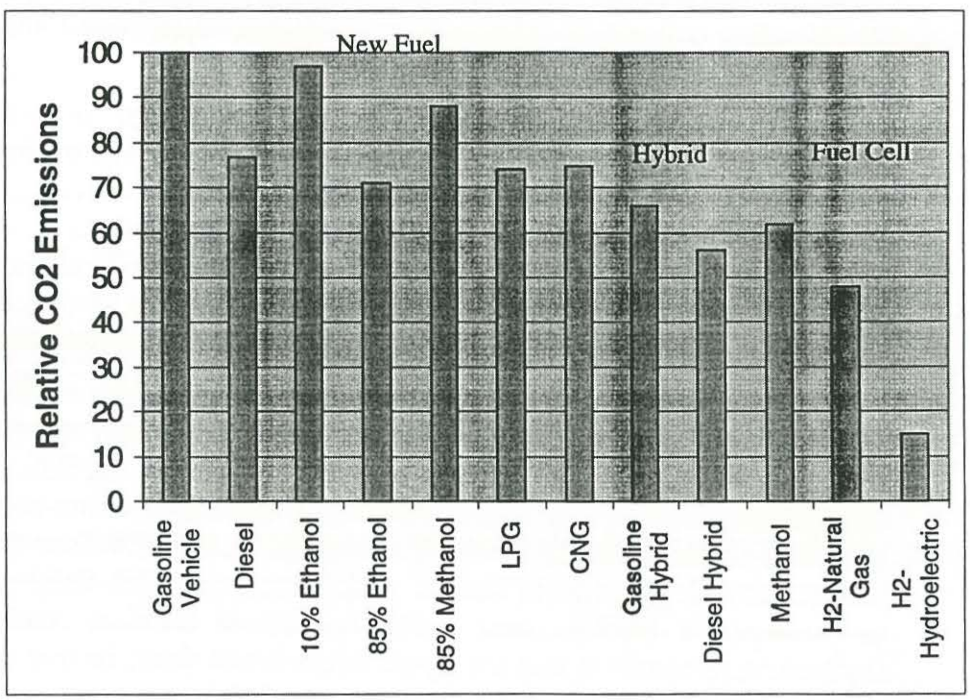
This technology is most promising for both near and long term development. However, the technology is being developed by major automakers in the global context and there is little

Canada can do to accelerate either its development or introduction to the comparatively small Canadian market. Furthermore, the technology is barely beyond proof of concept stages and it is difficult to imagine substantial quantities of hybrid vehicles being made available in the short term [Toyota recently announced plans to increase Prius production]. Finally, it should be noted that hybrid vehicle technology currently is only being developed for light duty vehicle applications. Undoubtedly there will be hybrid powertrain developments for commercial vehicles, but the success of the hybrid automobile is due largely to the short trip length and particular duty cycles that characterize urban driving conditions. Long haul transportation involving large tonnage vehicles may not be amenable to similar emission reductions through the application of hybrid powertrains.

New Technology

Vehicular technology based on zero carbon fuels holds the greatest long-term promise for GHG emission reductions. Such technology would provide independence between vehicle use and GHG emissions, thus decoupling the patterns of vehicle use from climate change. The leading technological alternative for such zero emission transportation is the use of hydrogen fuel cells to provide on-board electricity generation from either a low hydrocarbon fuel (methanol, ethanol, natural gas reformed to hydrogen) or a zero emission energy carrier such as hydrogen or other new carriers such as Sodium Borohydride. The vehicle becomes powered by electricity with the attendant performance improvements that accompany that transition, but without the impediments imposed by storing energy in batteries. Fuel cell vehicles will achieve equivalent performance (performance, cost, duty cycle) to conventional fueled vehicles, but with huge emission reductions. The extension of the hybrid electric vehicle to include a fuel cell engine is an exciting possibility for technology development.

Graph 5 Relative Emissions from Different Fuel and Vehicle Technologies



GHG emission estimates from fuel cell powered vehicles resort primarily to emissions produced in vehicle manufacture and fuel production. Again referring to figure 1, emissions from fuel cell powered vehicles are estimated to be between 38% and 85% lower than conventional vehicles. One advantage of fuel cell vehicles is the opportunity to exploit very large economies of scale through multiple applications of the same technology. Canadian fuel cell and hydrogen production technologies lead the world. Ballard Power systems, Global Thermoelectric, Xcelsis, Hydrogenics, Greenlight Power, Powertech labs, Dynetek, Stuart Energy, Hydrogen Systems, Cellex and others are among the leading names in this industry – all are Canadian. Canada is furthering the development of these technologies through significant R&D funding initiatives led by the National Research Council of Canada, and an industry focus group 'Fuel Cells Canada' is playing a major role in coordinating the early demonstration and distribution of these technologies to point the way for future development. Even so, the technology is new and untested and there remain significant challenges to both proving performance and developing the necessary support infrastructure (from refueling stations to diagnostics and maintenance). These issues push the realistic time-frame for implementing zero emission fuel cell vehicle technology into the 10-15 year timeframe.

Conclusions On Transport To summarize the foregoing, transportation is the largest single sector for GHG emissions, not a surprising fact given the role of transportation in both domestic and commercial activities of Canadian society. Although there are a wide array of short-term measures which could reduce GHG emissions at low or even negative costs, the total reduction in CO2 emissions from these is estimated to be about 10 Mt in 2010. Extending the scenario to include feasible fuel substitution and new vehicle technologies, the Transport Table concluded that emissions reductions of up to 40 Mt in 2010 at a cost of $5/t may be possible. Even this most optimistic scenario leaves the Canadian Transportation sector short in emissions reductions, suggesting that price controls may be necessary if the transportation sector is to achieve Kyoto targets.

In the longer term, it is possible that new technical innovations, particularly with respect to hydrogen technologies, will introduce transportation technology that produces no emissions during use or production of fuel (manufacturing and salvage of transportation technology will still likely produce emissions).

8. Biomass Management and Sinks

Sinks, both geological and biological, have an impressive potential capacity for storing carbon, as well as some other very attractive features. Obviously a lot of R&D work has to be done, both generic and site-specific, before sinks could be implemented on a large scale, but there seems to be significant near- and long-term benefit in pursuing technologies relating to the capture and storage of carbon, with an emphasis similar to that accorded other GHG mitigation approaches.

Sinks could allow the continuing use of coal, which is abundant and cheap, and also of oil and natural gas. Some sink activities may be paid for by the economic revenue generated, for instance enhanced recovery of oil or enhanced coal bed methane extraction. Even when sinks result in a net cost, many of them seem to fall within the cost range of competitive options. Over time, carbon emissions are likely to take on an economic value in all cases, i.e there is no escape from the costs. Sinks are probably easier to implement politically than measures that restrict economic activity or options, as they pose less of a threat to core goals such as economic growth.

However, they are not without their critics. Their permissiveness for continuing use of fossil fuels is a double-edged sword, as it can be seen as inducing complacency and encouraging growth in GHG emissions, which might then be difficult to control. This perception provides some of the rationale for opposition to the inclusion of sinks in Kyoto accounting schemes. Other concerns relate to the security or permanence of these carbon stores, and the difficulties in quantifying and verifying the carbon stock changes that are associated with the 'additional activities' taken to create the sink .

From Minister Anderson's recent statement *(Anderson 2001)*, Canada's policy on sinks is that you account for carbon stored or disposed when that event happens, and you account for carbon released when it is actually released. That makes sense. How much of the uptake should be ascribed to human activities, and hence credited in the Kyoto accounts, and how much should be regarded as natural is obviously a thorny question, which will likely be decided politically. Biomass uptake allows for CO_2 to be taken directly from the atmosphere. Geologic disposal requires a fairly concentrated stream of CO_2, so it is best matched to large point sources, like fossil-fired generating stations which, according to the IEA *(IEA, 2000 at p.3)*, are responsible for about 33% of global CO_2 emissions, although less than 20% of emissions in Canada.

Geological Sinks. The major geological sinks include deep saline aquifers, depleted oil and natural gas reservoirs (mainly gas), coal beds where C02 can displace methane (coal bed methane or CBM), and oil reservoirs where enhanced oil recovery (EOR) is possible through CO_2 injection *(IEA 2000; Legg 2000; Gunter 1998; Reeve 2000).* Oceans are considered to be a large potential sink for further carbon sequestration, in the order of 1000 Gt C. Costs for the UK were estimated at about $21 per tonne C, exclusive of compression. Ocean sequestration would require access to sites at depths of 3 000 metres, and transport both overland to the coast and thence to the deep ocean site, which are long distances for most Canadian sources of carbon emissions. It would raise issues of environmental impact around the injection site, and the security with which the gas could be contained. Since Alberta and Ontario produce about two-thirds of Canada's GHG emissions, and since there are ample land-based storage opportunities in Canada, Canada is not pursuing ocean disposal as a near-term option, although we participate in some international studies *(Gunter, 1998; Reeve, 2001).*

Estimates of storage potential vary widely, pointing to a need for a more thorough inventory of sites and their potential. Globally, aquifers and depleted reservoirs seem to have a potential in the hundred Gt C range. Coal beds and EOR are in the tens to hundreds -Gt C range. Coal bed methane is particularly well suited to countries that have abundant coal and little natural gas, like China and India, as it could be seen as a method of coal gasification.

Compared to annual global anthropometric GHG emissions in the 5 Gt C range, these storage capacities are very large. For EOR, the retention time is believed to be perhaps as short as tens of years, whereas it is of the order of 100 000 years or more for the other options.

In Alberta, recent estimates for storage potential are in the range of 5 Gt C (20 Gt CO_2) for coal beds, depleted reservoirs, and aquifers, and 16 Mt C for EOR. Alberta's annual emissions are in the 55 Mt C range, about a third of Canada's total. This suggests that there is enough geologic capacity to dispose of Alberta's entire emissions for many years to come. The challenge is to develop and prove the safety, environmental impact and cost effectiveness of this approach. A current EOR project at Weyburn Saskatchewan will result in the storage of about 0.5 Mt C per year for the next decade or so.

According to Gunter *(Gunter 1998)*, capture and sequestration in Alberta could get to about 10 Mt C per year in 2010, or about one-fifth of Canada's required reduction (Kyoto Gap), although achieving this goal in that time frame would be a major challenge.

Concentrations of CO_2 in flue gas range from 4% for natural gas combined cycle plants to 14% for pulverized coal plants. Using oxygen instead of air increases CO_2 concentrations to 90% but this also requires high energy. Carbon can be captured post-combustion from the flue-gas streams for coal or gas-fired plants, or pre-combustion by separating the nitrogen from air, and converting the carbon, oxygen and fuel into carbon dioxide and hydrogen. The IEA GHG R&D programme suggests that capture methods could produce an 80% reduction in CO_2 emissions, with a corresponding reduction of about 10% in generating efficiency *(IEA 2000)*.

Separating the carbon is the most expensive stage, costing about $10 per tonne C ($30 to $50 per tonne CO_2). However, the in the case of EOR and CBM, the revenue stream from the enhanced oil or methane recovery may result in a net benefit, or negative cost. Transportation through pressurized pipelines and geological storage should each add less than a dollar per tonne C. Overall, capture and storage will add about 1.5 - 3 US cents per Kilowatt hour to the cost of electricity. Prices for electricity in the OECD countries in 1998 were in the range of 7 - 14 US cents per kwh for domestic use, and 4 - 9 cents per kwh for industrial use *(IEA 2000)*, so the additional cost is not negligible.

For Canada, Reeve *(Reeve 2000)* notes the potential for overall capture and storage costs as low as $7 per tonne C. Reduction to about $5 per tonne C would allow widespread deployment, and would offer Canada continuing use of coal, which can be supplied at the equivalent of $2 per barrel of oil. Three-fourths of the point sources in Western Canada are for electricity generation. About 0.4 Mt C per year could be stored in oil reservoirs and used for EOR at a net cost of about $4 per tonne C, while 10 Mt C per year could be stored in deep coal seams or aquifers at $10 per tonne C. The limit is the amount of CO_2 available, and competition from other options, etc., rather than storage capacity.

Technological requirements in this area are for better assessments of geologic potential, field tests to determine fate of CO_2 injected, as is being done at Weyburn, cost reductions for CO_2 separation technologies, and more experience in the use of hydrogen for turbines. *(Reeve 2000, IEA 2000; Ampere 2000)*. Also required are assessments of regulation, tax and royalty frameworks, an inventory of sources and sites, and institutional development for communication, financing and management of projects (*Reeve 2000*).

Biological Sinks Through photosynthesis, plants have the ability to use the sun's energy to remove CO2 from the atmosphere and create a biomass (i.e. the plants themselves) which is both a carbon and an energy store. When the plant material is burnt, consumed by animals or dies and decays, the C in the biomass is returned to the atmosphere, thus completing the biosphere C cycle.

Canada is one of the very few developed countries of the world where our GHG emissions from fossil fuels (ca. 180 Mt C/yr) are dwarfed by the flow of C through our biosphere (est. at >2800 Mt C/yr). Although Canada is home to only 0.5% of the world's population, the nation is steward to approximately 10% of the world's forests. That forest resource, and Canada's vast agricultural lands have allowed this country to provide about 5% of the world's fibre products and 2.5% of global grain production.

Currently, Canadian agriculture is a major source of non-CO2 emissions (about 10% of the total) and there is a question about whether our national forest stocks are currently increasing or decreasing. However, managing GHG emissions and biosphere C stocks has never been a priority for Canada's agriculture and forestry sectors and many opportunities exist for decreasing agricultural GHG emissions while increasing the amount of C which is taken up and stored in forests or in agricultural soils.

Some of the management strategies or 'technologies' for C sequestration are well known and could be implemented with appropriate incentives. For example, use of low-till agriculture as an alternative to plowing, improved pasture management, more optimal use of fertilizers, or changes in crop rotation strategies are all known to increase soil C reserves. In forestry management, changes in harvesting strategies, prompt replanting after harvest, pre -commercial thinning of forests, fertilization, planting trees on abandoned agricultural lands and improved fire and pest control will all work to increase C stocks.

There are also a number of new technologies which could be developed to enhance the ability of the Canadian biosphere to take up and hold atmospheric carbon. For example, crop plants could be selected with root systems or silage that decompose more slowly. Given that most crops have a tonne or more C per hectare in below ground biomass at the end of each season, and given that there are more than 30 M hectares of cropland in production in Canada every year, the opportunity is significant. In forestry, selection of tree seedlings for replanting that grow 20-30% faster than average, or that are resistant to insect pests could have a major impact on Canada's carbon economy in coming decades.

A major technological issue for using biosphere C sinks involves the need for cost-effective tools to quantify and verify carbon stock changes and associated non-CO2 GHG emissions. The biosphere C stock is Canada is very large and measuring the C stock changes that occur with additional activities can be a challenge since the background levels are both high and variable. New instruments and measurement strategies are currently under development for the rapid quantification of soil C content, forest biomass, N2O and methane emissions. Measurement and modeling tools are also being developed to scale the site specific measurements to regional and national levels.

These measurement and verification tools are perhaps the most important technologies that need to be developed for large scale implementation of biosphere C sequestration. The return on the investment should be very high since changes in biosphere management in Canada should be able to take up and hold many tens of millions of tonnes of C per year. At $100 per tonne, the opportunity is in the billions of dollars per year. In addition, there are cobenefits associated with many C sequestration technologies including enhancing biodiversity, sustainable forestry and agriculture, soil conservation, rural development and new products for farmers.

Through biosphere C management, Canada should be able to increase the 'minimum monthly balance' in it's 'national C account'. It should also be able to divert a portion of this additional biomass to provide some of the energy, chemicals and materials that are now derived from fossil fuels. Canada has a major opportunity here. For example, the *residual* biomass from Canada's current agriculture and forestry sectors (i.e. 44 Mt C/yr) has an useable energy content of about 1.6 exajoules, an amount equivalent to over 20% of the energy that Canada extracts from all the fossil fuels consumed in this country in a year (*Layzell, 2001*).

Full biosphere C management will require the development of a plethera of new process engineering and bio-technologies that will facilitate the movement towards a new, bio-based economy. This represents a major thrust in laboratories around the world, but especially in the USA where the primary driver is 'energy security' rather than GHG emission reductions (*Lugar and Woolsey, 1999*).

9. Conclusions: Outstanding gaps and opportunities for Canada

- Canada's GHG emissions continue to grow. The current Action Plan address only one-third of Canada's Kyoto Gap, and half of those reductions are through sinks and international credits. Also, the Gap is likely to be larger than projected in government documents.
- Technology development clearly has a role to play in meeting commitments for thepost-Kyoto period, which are likely to more stringent, through greater efficiencies, changes in the fuel mix, new approaches to energy systems, and the capture and sequestration of carbon.
- Given the projected increases in Canada's already high use of energy, and the likelihood of further growth with energy exports and tar sands development, carbon capture will be important for Canada.
- Canada has a very large landmass with extensive forests and agriculture , so biomass mangement must be important. It provides a general and diffuse capture mechanism. But agriculture (and to a lesser extent, forestry) represents a significant source of GHG emissions in Canada, so if we are going to look to these sectors for enhanced C sinks, or for a source of biomass energy, we will need the technologies and management strategies to produce this biomass carbon stock with few or no emissions of non-CO_2 GHGs.
- A big technology challenge for biosphere C sinks is related to the need to quantify and verify the increases in C stocks and to show that these increases are associated with 'additional activities'. It is also imperative to show that the C stocks (geological or biosphere) will have reasonable permanence, or at least that subsequent decreases in C stocks can be readily quantified.

- Transport is a large and growing sector, - so efficiencies and fuel switching will be important. While it will take time to make changes to the infrastructure, the longer term focus shuld be on lower carbon fuels, including hydrogen.
- Electricity underlies our economy and will continue to grow, though not as fast as in the developing countries. Development aimed at developing lower-or non-carbon sources, and in particular reducing their costs, will be essential, as will the development of lower-cost capture and sequestration options. .
- Buildings - Commercial and institutional buildings seem to have more promise for emission reductions at lower cost than residential.
- Oil and gas production is alarge and growing source of emissions. Solutions needed, including carbon capture and sequestration.
- Given the large scale of Canadian energy use (absolute and per capita) and GHG emissions, demand management and efficiency have to be major considerations in all sectors.
- While technology development is fundamental in climate change policy, implementation will require major changes in attitudes and behaviour, individually and collectively.
- Canada can make a contribution to world climate change technology in many areas based on our knowledge and experience, especially in oil and gas proudction, carbon capture and sequestration, biomass, transport, alternative fuels, including hydrogen, and in the generation, transmission and use of electricity. We should continue to invest in longer term development in these areas.
- In the near and medium term, it will be important to improve mitigation by enhancing efficiencies, educating the public, using energy wisely, and lowering the overall carbon content. Stronger incentives will be required, through price mechanisms (taxes or trading schemes), and regulatory action and standards. In the longer term, given the pressures of population and economic growth, and increasing demand for energy services (mobility, floor space, products, information), new systems will be required, emphasizing sequestration on the one hand, and low or non-carbon energy sources and systems on the other. Canada is well positioned to move toward a non- or low-carbon hydrogen/electricity system, and to develop both biomass and geological sequestration.

Bibliography and References

Ampere 2000, Ampere Commission, ***Report to the Belgian Government on Future Electricity Supply,*** Section D: Technologies Gaz, Gaz-Vapeur, Charbon et Cogeneration, especially pp. 126-154 on capture and sequestration, Brussells, 2000.

Anderson 2001, Anderson, David, Canadian Minister of the Environment, ***The Kyoto Protocol: The road ahead,*** Press Release, Canadian Mission to the European Union, May 17, 2001. **www.dfait-maeci.gc.ca/eu-mission/anderson_oped-e.html.**

Goodale 2001, Goodale, Ralph, Canadian Minister of natural Resources, ***Goodale touts big power sales to US,*** Toronto Globe and Mail, September 7, 2001.

Government of Canada 2000, ***Action Plan 2000 on Climate Change,*** Ottawa, 2000.

Gunter 1998, Gunter, W.D. et. al., ***Large C02 Sinks: Their role in the mitigation of greenhouse gases from an international, Canadian and Alberta perspective,*** Applied Energy 61 (1998), 209 - 227.

IAASA 1998, ***Global Energy Perspectives,*** International Institute for Applied Systems Analysis and World Energy Council, Cambridge University Press, 1998.

IEA 2000a, ***World Energy Outlook 2000,*** International Energy Agency, Paris, 2000.

IEA 2000b, ***Energy Technology and Climate Change: A Call to Action,*** International Energy Agency, Committee on Research and Technology, Paris, 2000.

IPCC 1995, ***IPCC Second Assessment, Climate Change 1995, A Report of the Intergovernmental Panel on Climate Change, Figure 1(b)***

IPCC 2000, ***Summary for Policymakers, IPCC Special Report on Land Use, Land Use Change and Forestry (LULUCF)***, 2000.

IPCC 2001a, ***Summary for Policy Makers (SPM) of the IPCC WG III Assessment Report on Mitigation,*** approved at 6th Session of WG III, Accra, Ghana, 28 February - 3 March 2001. (This has the Table SPM - 1)

IPCC 2001b, ***Technical Summary, Climate Change 2001: Mitigation, A Report of WG III of the IPCC***, 2001.

IWG 2000, Interlaboratory Working Group, ***Scenarios for a Clean Energy Future,*** NREL/TP-620-29379. Nov. 2000

Layzell, 2001, Layzell, D.B. Canada's Green Advantage for a Bio-based Future. Report prepared for Industry Canada for the Vision 2020 BioProducts Leaders Workshop, Ottawa. 7-8 February 2001

Lugar and Woolsey, 1999. Lugar, Richard and Woolsey, R. James . The New Petroleum. Foreign Affairs, Jan/Feb. 88-102

Legg 2000, Legg, John , M. McDonald, and M. Wilson, ***Canada's National Initiative on C02 Capture and Storage,*** 5th International Conference on Greenhouse Gas Control Technology, Cairns, Australia, August 2000.

Medlock and Soligo 2001, Medlock, K.B. and Roland Soligo, The Energy Journal, Vol. 22, No. 2, 2001

NCCP 1999a, Analysis and Modelling Group, National Climate Change Process, ***Canada's Emissions Outlook: An Update,*** Natural Resources Canada, December 1999

NCPP 1999b, Technology Issues Table, National Climate Change Process, ***Enhancing Technology Innovation for Mitigating Greenhouse Gas Emissions***, Ottawa, December 1999

NCCP 2000a, Summaries of the Options Tables Reports, Briefing Book for Ministers, National Climate Change Process, March 2000.

NCCP 2000b, National Climate Change Process, ***Canada's National Implementation Strategy on Climate Change***, October 2000.

NCCP 2000c, Analysis and Modelling Group, National Climate Change Process, ***An Assessment of the Economic and Environmental Implications for Canada of the Kyoto Protocol,*** November 2000.

NCCP 2000d, Electricity Table, ***Executive Summary of the Options Report, Briefing Book for Joint Meeting of Energy and Environment Ministers,*** March , 2000.

NRCan 1997, Natural Resources Canada, ***Energy Outlook 1996 - 2020,*** Ottawa, 1997.

NRCan 2000, Natural Resources Canada, ***Energy in Canada 2000,*** Ottawa, 2001.

Patterson 1999, Patterson, P., ***Reducing Greenhouse Gases in the U.S. Transportation Sector,*** SAE Government and Industry Meeting, Washington D.C. April1999.

Patterson 2000, Patterson, P., ***Quantifying the Fuel Use and GHG Reduction Potential of EV's and HEVs,*** EVS-17.

Reeve 2000, Reeve, D.A. ***The Capture and Storage of Carbon Dioxide Emissions - a significant opportunity to help Canada meet its Kyoto targets,*** prepared for Office of Energy Research and Development, NRCan, Ottawa, 2000.

Schipper 2001, ***International Comparisons of Sectoral Carbon Dioxide Emissions using a Cross-Country Decomposition Technique,*** The Energy Journal, Vol. 22, Number 2. Pp 35 - 76, 2001.

Statscan 2001, Statistics Canada, ***The Daily, March 1, 2001, Electric Power Statistics***, http://www.statcan.ca/Daily/English/010301
Transport Canada 1999, Transport Canada, ***Transportation and Climate Change: Options for Action,*** Options Paper of the Transportation Climate Change Table. Nov. 1999.

Wallace 2000, Wallace, D. ***Capture and Storage of CO2: What Needs To Be Done?,*** International Energy Agency, November 2000.

Worldwatch 1999, Worldwatch, ***Vital Signs***, Washington, 1999.