ENERGY AND CLIMATE CHANGE

– A Canadian Engineering Perspective –

A Report of the

Canadian Academy of Engineering

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MISSION STATEMENT

The Canadian Academy of Engineering is an independent, self-governing and non-profit organization established in 1987 to serve the nation in matters of engineering concern. The Fellows of the Academy are professional engineers from all disciplines and are elected on the basis of their distinguished service and contribution to society, to the country and to the profession.

The Academy is self-financing and does not receive grants from government although it may carry out studies and surveys on a contract basis. The Fellows of the Academy can therefore bring into corporate activity, in a completely independent manner, the wide experience and expert knowledge which they have acquired as practicing members within the engineering profession of Canada, a profession with 160,000 members currently.

The mission of the Canadian Academy of Engineering is to enhance, through the application and adaptation of science and engineering principles, the promotion of well-being and the creation of wealth in Canada.

The Academy fulfills this mission by:

- promoting increased awareness of the role of engineering in society,
- recognizing excellence in engineering contributions to the Canadian economy,
- advising on engineering education, research, development and innovation,
- promoting industrial competitiveness while preserving the environment in Canada and abroad,
- speaking out on issues relevant to engineering in Canada and abroad,
- developing and maintaining effective relations with other professional engineering organizations, academies and learned societies in Canada, and abroad.

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EXECUTIVE SUMMARY

The Canadian Academy of Engineering is undertaking an "Energy and Climate Change" study in accordance with its mandate of: "…speaking out on issues relevant to engineering in Canada and abroad". In September 2000 a Working Group was formed to define what role the Academy could play in the Energy / Climate Change debate. The Working Group reviewed a wide range of existing data on present and projected energy demand and supply systems. The results of this review were presented to the membership of the Academy at the 2001 Annual General Meeting. This report contains basically the information as presented at that time.

While the development of a long-term, sustainable energy strategy involves many different aspects, one common factor is **technology.** The Academy, through the vast knowledge and expertise of its members, can make an important contribution to the development of such a strategy by providing a critical, unbiased review of the technologies relevant to both, the energy demand and the energy supply system.

The highlights from the overview by the Working Group were:

- the global demand for energy will increase by a factor of 5 - 6 during the next century, with nearly all of this increase coming from developing nations, because of population growth and growth in GDP
- a majority of scientists agree that the climate has already been affected by human activities since the beginning of the industrial revolution
- while there are sufficient conventional (hydro-carbon based) sources of energy to meet even the most extreme projections of future demands, the environmental consequences would be unacceptable
- a wait-and-see attitude is not acceptable for evaluating definitive climate changes, and hence for developing an energy strategy capable of coping with changing circumstances
- future energy use scenarios, developed for Canada and for the world, show that even the most optimistic scenarios will lead to significant increases in the average temperature of the earth's surface
- to accommodate the large increase in the demand for energy without major environmental problems, it will be necessary to greatly expand the choice of energy sources and at the same time increase the efficiency of energy use
- the key factor in expanding the choices of affordable and acceptable energy sources, as well as reducing the energy demand, is the development of new technologies

- the cost of delivering energy will always need to be carefully considered, since some of the most desirable energy sources from an environmental point of view are also the most expensive
- a long-term, sustainable energy strategy implies that it meets the needs of the present without jeopardizing the needs of future generations in any respect, economically, environmentally, and socially
- the complexities inherent to the actual development of sufficient and adequate new energy technologies will involve immense engineering challenges
- the Canadian Academy of Engineering can make a unique contribution to the debate and to the development of an energy strategy by critically assessing the emerging energy technologies and evaluating their potential for helping to solve the "energy" problem

The conclusion of the Working Group is that hydrocarbon-based energy sources should be able to satisfy the six-fold increase in the demand for energy, which is forecast for this century. However, the risk that such a strategy would have significant effects on the climate, and therefore on the global environment, is probably too large to accept.

A long-term, sustainable energy strategy needs to be developed, which will necessarily require a larger choice of energy sources and energy technologies, than presently available. Given the immense challenges of developing energy technologies and the collective expertise of the members of the Canadian Academy of Engineering, it is evident that the Academy can play an important role in the assessment of those already available, as well as entirely new energy technologies.

ENERGY AND CLIMATE CHANGE

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INTRODUCTION

The Canadian Academy of Engineering (CAE) is an independent, self-governing and non-profit organization – one of the learned societies in Canada. The mission statement of the Academy includes the following wording:

> *to enhance the promotion of well-being and the creation of wealth in Canada ..by.. speaking out on issues relevant to engineering in Canada and abroad*.

An adequate, secure supply of energy is essential for the general well-being of any modern society. Most members of such a society, however, have become aware of the ongoing debates on how much the ever-increasing demand for energy has started to affect their local, as well as the regional and global climate. Given the strong dependency of energy demand and supply systems on technology, the **Energy and Climate Change** issue is obviously a prime subject to be addressed by an academy of engineering.

The Development and Implementation Committee of the CAE initiated an Energy and Climate Change study in September 2000 by forming a small Working Group. As a first phase, the Working Group compiled and analyzed existing data on the current and the projected energy demand and supply situation in Canada and globally, in order to obtain a comprehensive understanding of the issue. This report contains an overview of the findings of the first phase of the study.

Using the vast pool of knowledge and expertise of its members, the Academy can, with modest financial support from other agencies and organizations interested in the development of a long-term, sustainable energy strategy, make a contribution to the development of such a strategy for Canada, as well as for other countries.

The ultimate goal of this study by the Academy is therefore to provide unbiased, reliable and up-to-date information of technologies relevant to energy demand and supply systems, for the benefit of decision makers in the public and private sectors, as well as for the public in general. The Academy believes that sound technical information is essential to the development of a long-term, sustainable energy strategy.

The information presented in this report is not intended to be an all-inclusive overview of the Canadian and global energy situation, but rather some examples of existing and forecast conditions. The intent is to provide arguments for a discussion on the need for a long-term, sustainable energy strategy. The concept of a *long-term, sustainable energy strategy* needs to be defined so that there can be a meaningful discussion of this concept.

In the original proposal of this study to the Board of Directors of the Academy, *sustainability* was defined as it has been used in several international publications:

practicability (availability and accessibility of each energy option), and acceptability (social acceptability, in its broadest sense, including environmental protection, particularly minimization of climate change due to GHG emissions, public health and safety, and fairness to suppliers or recipients)

In simpler terms, sustainability is here defined as being *practical* (available and accessible) and *acceptable* (socially, environmentally and economically). There are several market driven concepts in this definition of sustainability, not only in the word economical, but also in the words practical and acceptable, both words being basic to a market driven economy. What is not practical or acceptable will not sell.

Only the words social and environmental point at the need for a long-term vision and commitment to a strategic R&D program in order to satisfy the concept of enduring. It would be desirable to add to this the term *enduring*, meaning that energy has to be available for the present as well as the future needs.

Sustainability equates to a continuing, efficient energy utilization, based on an adequate production, without harming society in any way, now or in the future. This implies an expansion of energy choices, not just in the development of new energy sources, but also new conversion and utilization technologies. Sustainability is not just an environmental or climate issue, it is as basic as sustaining the world's energy future. To quote the 1987 Brundtland Commission report: "Sustainable development can meet the needs of the present without jeopardizing the needs of future generations"

THE EARTH'S CLIMATE

A recently published report of the UN Inter-governmental Panel on Climate Change (IPCC) states "that it is at least 90% certain that temperatures will continue to rise" if no changes are made to the energy supply system (Ref. 1). Figures 1 and 2, obtained from information in the IPCC report, show how data, collected from many different sources, do provide strong evidence of human influence on the earth's average surface temperatures during the last 140 and the last 1000 years, as well as on the concentration of three Greenhouse Gases (GHGs) in the earth's atmosphere since the beginning of the 19^{th} century – the industrial era.

Figure 1a presents annual temperature readings, averaged over 10-year time periods. During the last century the global average surface temperature appears to have increased by about 0.6^{oC}.

Figure 1b shows the average surface temperature of the Northern Hemisphere for the past 1000 years, averaged over 50-year time periods. This information has been reconstructed from proxy data (such as tree rings, corals and ice cores) for the period before 1850, but calibrated against thermometer data over a 100 year period from between 1850 and 1950. Accurate thermometer data have been available since 1850. Although the accuracy of the data is obviously less reliable from the earlier years, it is quite evident that the rate and duration of warming during the 20^{th}

century has been greater than in any of the previous nine centuries. Indeed, the years of the 1990's have constituted the warmest decade, and 1998 the warmest year, of the millennium.

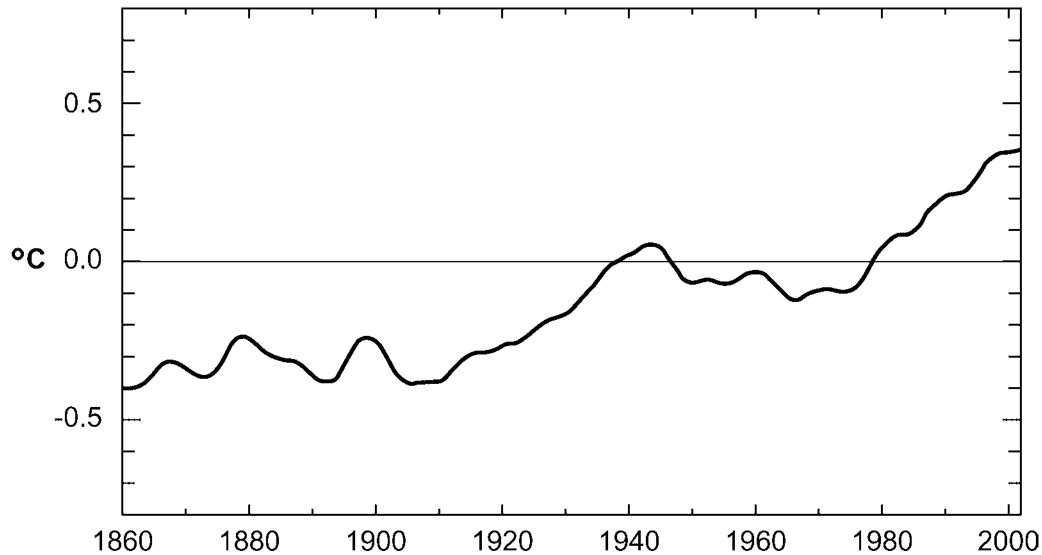

Figure 1a. Variations of the earth's surface temperature for the past 140 years

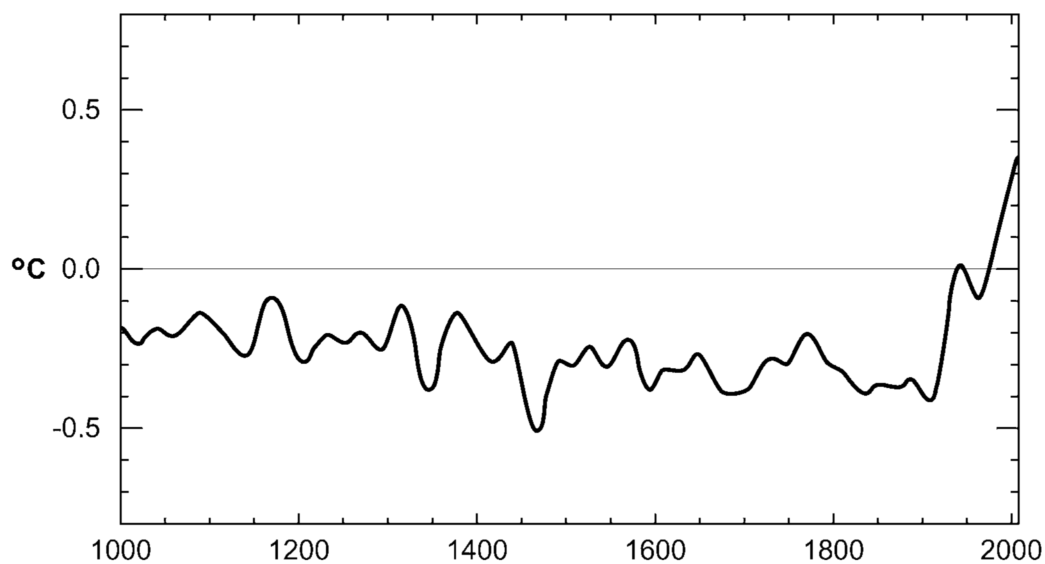

Figure 1b. Variations of the earth's surface temperature for the past 1000 years

Figure 2 indicates the human influence on the atmosphere since the industrial era. GHG data in ppm/ppb from ice core samples from several sites in Antarctica and Greenland have been supplemented with direct atmospheric readings over the last few decades, to provide the information over the 1000 year time span.

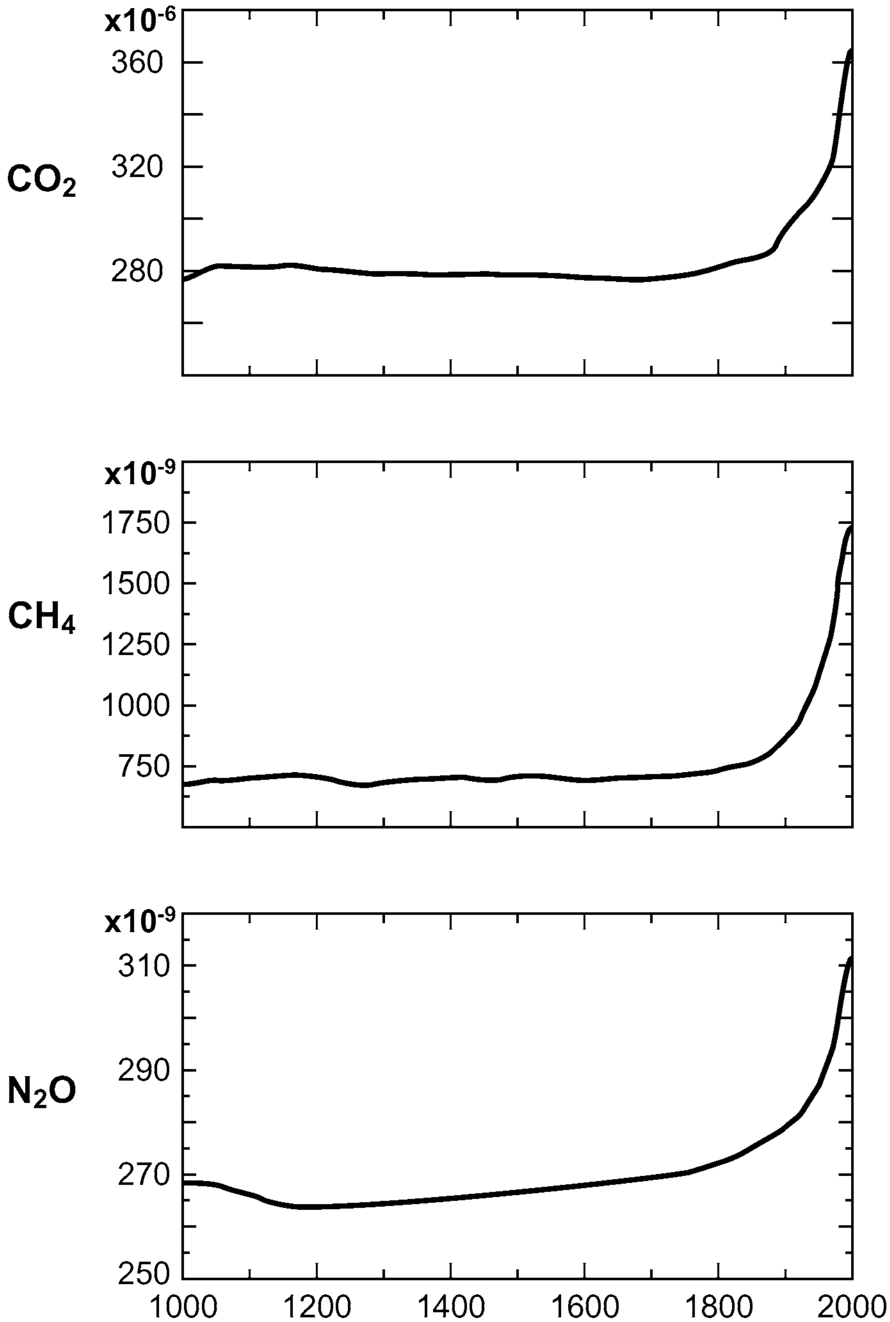

Figure 2. Global atmospheric concentrations of three greenhouse gases

The Science Academies of some 17 countries, including Canada, have recently called for "prompt action to reduce the human production of Greenhouse Gases that are warming the planet". However, there are also reputable scientists still doubting that the collected evidence is indeed sufficient to justify making substantial changes to the existing energy supply system, mostly because of the major economic consequences associated with such changes. This report is not going to resolve this very important question. It became quickly evident to the Working Group that the vast majority of scientific papers have presented evidence that human activities are indeed affecting the global climate. The position taken by the members of the Working Group, and supported by the Board of Directors of the Academy, was therefore that any study of a long-term energy strategy needed to include the possibility of climate change. A sound engineering approach dictates that a *wait and see* attitude is not acceptable, because the risks are too great, while with current technologies the time necessary to be able to make substantial changes to the energy supply system is far too long.

CANADIAN ENERGY SUPPLY AND DEMAND

It has become a well-known fact that Canadians, together with their neighbours to the South, are the largest consumers of primary energy per capita in the world. The 1998 figures of the annual, per capita consumption of energy clearly illustrate the large differences between the various regions of the world (Ref. 3) (NB: 1 GJ = 10^9 Joules)

North America:	360 GJ
Europe, Japan:	190 GJ
China:	42 GJ
Africa, India:	25 GJ

The striking difference in the demand for energy between North America and Europe, two equally developed regions, can be only partially explained by the differences in climate and geography (colder winters and greater distances between economic centers). It would be interesting to study the differences in the actual demands in greater detail to be able to decide if the North American demand can be reduced, by the application of new technologies, or through changes in life style.

Energy Demand

For most of the last century there existed a direct correlation between the per capita GDP of a nation and its primary energy use. However, the oil crisis of the seventies changed this. Conservation, increased efficiencies, and the development of new technologies have made it possible to have increases in GDP/capita without proportional increases in the demand for energy. For Canada, an annual economic growth rate of about 2% over the next 25 years would result in a 70% increase in GDP. In the same time period, the population of Canada is estimated to grow by about 20%. However, the total annual demand for energy is expected to increase by only about 25%, with very little increase in energy consumption per capita-year. The annual demand for energy in Canada is therefore expected to increase from the current 8000 PJ to 10000 PJ (1 Peta Joule = 10^{15} Joules) by 2025.

Currently, about 42% of the energy is used for industrial processes, 25% for transportation, 30% in buildings and about 3% represents a non-energy use of hydro-carbons in the manufacturing of products (plastics, etc.) (Ref. 4). The introduction of new technologies over the next 25 years may well change these percentages of the use of energy. There is still considerable scope for conservation of energy in the design of buildings, both commercial and residential. New technologies in the area of transportation may also have substantial consequences for the energy demand.

Energy Supply

Having looked briefly at the projected energy demand situation in Canada over the next 25 years, it is also of interest to look at some recent trends in the Canadian energy supply system, to see if any major problems can be expected.

Oil Production and Oil Reserves

During the last decade the annual production of oil in Canada has increased by about 25%. However, just in the first 5 years of the decade (1990 - 1995) the export of oil to the US increased by some 95%. This substantial increase was partly made possible because of the rapid development of the oil sands in Western Canada. Currently planned further developments of the oil sands could increase the synthetic crude production by up to an additional 600%.

At the same time, offshore oil production along the East Coast of Canada (Hibernia, Terra Nova fields) is expected to increase by about 300%. The proven reserves of conventional oil in Canada will be sufficient for about ten years, but this number merely reflects the economics of drilling to establish the size of the oil reserves. Canada's total reserves are estimated at 12,000 million tonnes (equivalent to 500,000 PJ), (Ref. 5). Including unconventional sources of oil (oil sands and offshore) it is estimated that Canada's production of oil could last another 400 years.

Gas Production and Reserves

During the last decade the annual production of gas in Canada has increased by about 45%. However, over the same time period exports of gas to the US have increased by some 250%. Additional gas reserves are known to exist in the Mackenzie Valley and offshore on the East Coast of Canada. The normal practice is to have a proven gas reserve for a 30 year time period. The total gas reserves in Canada, including the offshore reserves, are estimated at $8{,}000 \times 10^9 \, m^3$ (equivalent to 300×10^6 PJ) (Ref. 5).

Coal Production and Reserves

In general coal represents the lowest-cost energy supply (electricity generation) option. This is true in Canada, as it is in most other parts of the world. For instance, at the present time three new coal-fired power plants are being planned or are already under construction in Alberta, with a total capacity of 1700 MW. The total estimated reserves of coal remaining in Canada are about 21,000 million tonnes (equivalent to 600,000 PJ) (Ref. 5).

Other Energy Sources and their Reserves

Currently about 78% of the Canadian energy demand is supplied from hydrocarbon-based sources (oil, gas and coal).

The largest non-hydrocarbon based source of energy in Canada is hydroelectric power, which produces annually about 350 TWh of electricity – this equates to 1200 PJ, or approximately 15% of the total energy demand. The total potential of hydroelectric power in Canada is estimated at 650 TWh, or about twice the currently installed capacity (Ref. 5).

Next in magnitude is nuclear power, which supplies about 100 TWh of electricity per year – which equates to about 350 PJ, or 4.5% of the total demand (Ref. 6). Canada has some of the richest uranium deposits in the world, and a large potential for increasing this source of energy supply, both in Canada and abroad.

Other non-hydrocarbon based sources of energy are often referred to as the *renewables*, and they include solar, wind, tidal and biomass. At the present time they provide relatively small amounts of energy in Canada, but their potential is significant.

This first phase of the study did not include an assessment of the various energy technologies, inherent to the development of renewable energy sources, conservation and energy efficiencies, as well as any new sources of energy. It is the intention to cover such an assessment in a second phase of this study.

GLOBAL ENERGY SUPPLY AND DEMAND

At the present time Canada's consumption of primary energy is about 2.5% of the world's total, but its share of world energy production is about 4.5%. Clearly, Canada is one of the world's net energy exporters. Its total energy production rates fifth, after the USA, Russia, China and Saudi Arabia

As mentioned earlier, the principal drivers of the increased demand for energy worldwide are population growth and economic development. The most recent forecast sees the world population peak at about 10 billion around the end of this century (current world population is about 6 billion). Figure 3 shows estimates of the world population between 9 and 12 billion by the year 2100, (Ref. 7).

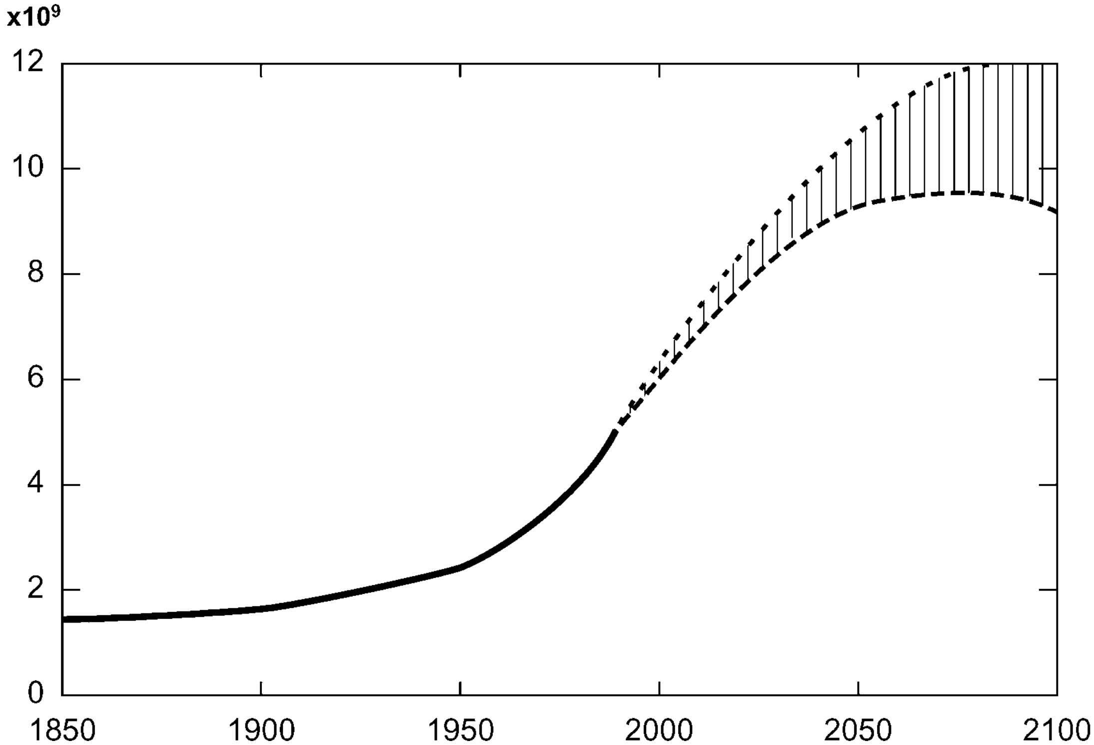

Figure 3 Estimates of World Population

A far more important number than population is GDP/capita, representing economic growth. Whereas the economic growth rate of developed nations is on average 2% per year, for the large developing nations the GDP/capita is expected to grow at up to 8% per year. The combination of population and economic growth leads to a forecast of an increase in the worldwide demand for primary energy by a factor of 4 to 5 over the next 100 years (Ref. 7). It is important to note that nearly all of this increased demand will come from the developing nations, and that it is assumed that all possible advantage has been taken from new technologies to use energy as efficiently as possible. Similarly, the annual 2% economic growth rate of the developed nations is not expected to lead to a corresponding increase in the demand for energy, because of the continuing development and introduction of new energy efficiency technologies and further conservation measures.

The total primary world energy demand in 1998 was on the order of 400×10^3 PJ, (Ref. 7). The estimated increase in this demand by a factor of 4 to 5 over the next 50 to 100 years could only be met from hydrocarbon based energy sources by very large increases in the supply of coal and synthetic crude oil from the oil sands. (The world's recoverable coal reserves are estimated at 10^{12} tonnes, or about 30×10^6 PJ. The globally recoverable unconventional oil reserves are estimated at 10^{12} barrels, or about 5.7×10^6 PJ (Ref. 5).

The environmental consequences of such a strategy would almost certainly be unacceptable at all levels – locally, regionally and globally – at least without the introduction of new technology. Currently available technologies for clean hydro-carbon based conversion processes are still expensive, and therefore not economically acceptable in the market place. Further development of already existing technologies, or indeed the successful development of entirely new technologies for alternative sources of energy, will hold the key for a long-term, sustainable energy strategy.

FUTURE ENERGY USE

The future energy situation, described earlier, leads to the conclusion that the development of other scenarios is required, capable of coping with the increased demands for energy without creating major environmental, social and economical problems. This study includes a brief overview of some scenarios developed by different organizations, that allow for a better understanding of the various parameters that will influence the way the world evolves, and that identify opportunities for Canada in such a changing world. Scenarios are neither predictions, nor forecasts. A particular scenario simply combines different mixes of energy sources, economic conditions and various technological opportunities. Several organizations have developed scenarios for long-term energy futures.

Future Canadian Energy Scenarios

One of the most recent scenarios for Canada was developed by Natural Resources Canada (NRCan); it is usually referred to as **Energy Technology Futures (ETF)** 2050. ETF 2050 was developed in consultation with a wide range of national and international energy experts. The different scenarios create visions of Canada's possible energy situation three to five decades into the future (Ref. 8).

Three independent drivers were identified for the development of four, somewhat extreme, scenarios. The three drivers were:

(1) *environmental etiquette* to reflect the perceived importance of environmental issues. When reaction to such issues is low the environmental etiquette is said to be “grey”. When awareness of environmental issues is high and taken into account in decision making processes, the etiquette is said to be “green”,

(2) *markets* to measure globalization of world markets. When products and capital flow freely across international boundaries, markets are said to be “open”. When nations focus on internal issues only, markets are said to be “closed”,

(3) *pace of innovation* to reflect the speed, at which Canada generates, develops and moves new ideas into the market place. A slow pace of innovation hinders economic growth, while a

rapid pace of innovation tends to increase the rate of change of capital investment in the energy infrastructure, to accept the integration of new technologies.

An assumption made for the development of the four scenarios is a Canadian population of 44 million by 2050. This will lead to different demographic circumstances, with their demands for an altered system of energy services, for instance in mobility and heating and cooling requirements.

The four scenarios developed for Canada in 2050 have been defined as follows:

(1) *Life goes on*: reflecting a slow pace of innovation, closed markets and a grey environmental etiquette (also referred to as "business-as-usual).
(2) *Grasping at straws*: reflecting a slow pace of innovation, open markets and a green environmental etiquette.
(3) *Taking care of business*: reflecting a rapid pace of innovation, open markets and a grey environmental etiquette.
(4) *Come together*: reflecting a rapid pace of innovation, open markets and a green environmental etiquette.

For each of these four scenarios ETF 2050 has developed the energy demands with fuel mixes and the resulting GHG emissions by sector. The results are shown in Figures 4 and 5. They show how the primary energy demand by 2050 can vary from a low of just over 10,000 PJ for the *Come together* scenario with 53% from fossil fuels, to a demand of 16,000 PJ for the *Life goes on* scenario, with 82% coming from fossil fuels.

Even more drastic are the differences in GHG emissions of a low of just over 200 million tonnes of CO_2 equivalent for the *Come together* scenario, to a high of over 1,000 million tonnes of CO_2 equivalent for the *Life goes on* scenario. The present level of GHG emissions is about 600 million tonnes per year (Ref. 9).

The methods used for developing these scenarios do not allow for catastrophic events, such as major natural disasters, or large geo-political upheavals resulting in large-scale wars.

The scenarios are meant to serve as a base for discussions on the development of energy strategies, nationally and internationally – they have been included in this report strictly as an example of the tools available for a meaningful discussion.

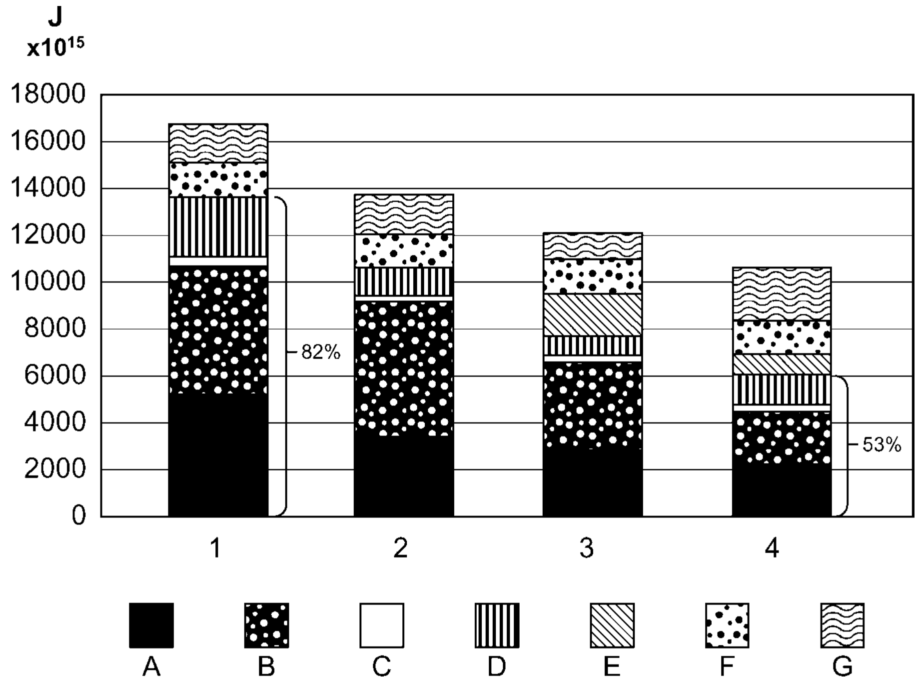

Figure 4. Primary Energy Demand by Source in 2050 for Four Canadian Scenarios: (A) Oil; (B) Gas; (C) LPG; (D) Coal; (E) Nuclear; (F)Hydro; (G) Renewable

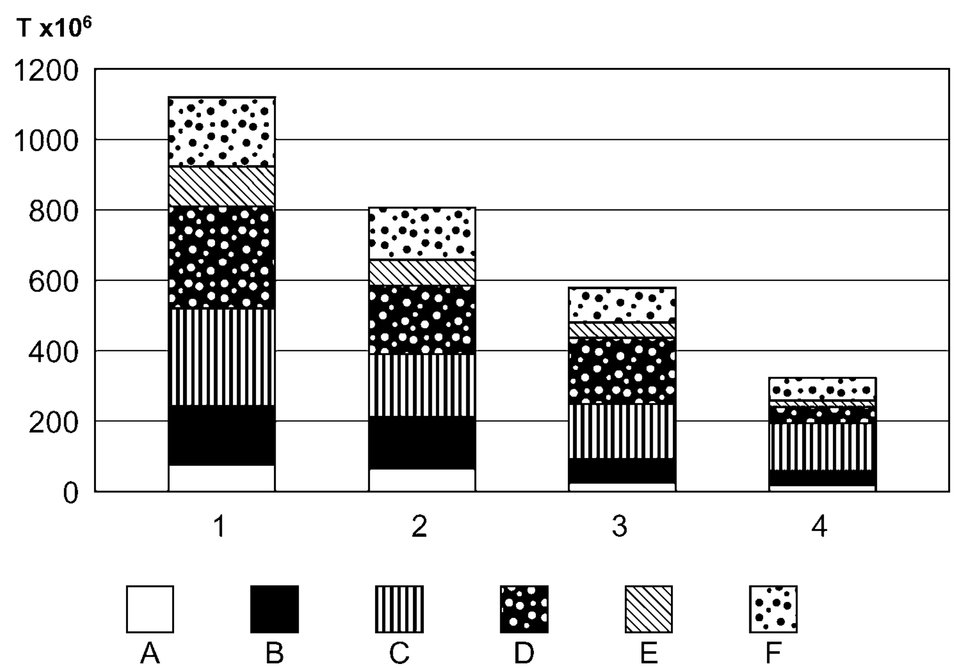

Figure 5. CO_2 Emissions by End Use Sector in 2050 for Four Canadian Scenarios: (A) Buildings; (B) Industry; (C) Transportation; (D) Electricity Generation; (E) Fossil Fuel Production; (F) Non-Energy

Future Global Energy Scenarios

Similarly to the NRCan ETF 2050 study of possible future energy scenarios for the Canadian situation, international agencies have carried out studies creating global future energy scenarios. Various studies tend to generate scenarios that are in general agreement. The most detailed study has been carried out by the **International Institute of Applied Systems Analysis (IIASA)** with the cooperation of the **World Energy Council (WEC)**; this is summarized below, (Ref. 7).

The IIASA study developed scenarios for three main cases, A, B and C, with three sub-sets in case A and two sub-sets in case C

A: **High economic growth** – technology and resource intensive, no CO_2 emission limits
- A1: high future availability of gas and oil
- A2: gas and oil scarce, massive return to coal
- A3: rapid technological changes lead to an increased use of nuclear and renewable energy sources and a phase out of fossil fuels for economic reasons, rather than due to resource scarcity (sometimes referred to as the *bio-nuc* scenario)

B: **Status quo** – achievable with little change, no CO2 emission limits

C: **Ecologically driven** – high non-fossil fuels
- C1: nuclear power is a transient technology that is entirely phased out by the end of the 21st century
- C2: a new generation of inherently safe nuclear reactors is developed with widespread social acceptability.

Case A clearly presents a future of ambitiously high rates of technological and economic progress. It is based on a conviction that there are essentially no limits to human ingenuity, and it assumes favorable geopolitics and free markets. By 2100 no distinction can be made any longer between developed and developing nations.

Case B represents a more modest middle course. It is more pragmatic than case A. All developments, both economical and technological, take place at a slower (though perhaps more realistic) pace. It relies heavily on a continuation of a fossil fuel supply, including the development of large amounts of the non-conventional hydrocarbon resources.

Case C is by far the most challenging. It is optimistic about geopolitics, as well as technology. It assumes, unlike case A, unprecedented international cooperation, focused explicitly on environmental protection and international equality.

The following table summarizes the characteristics for the six scenarios, while figure 6 shows the corresponding primary energy demand numbers for cases A, B and C, and figure 7 illustrates the resulting implications for the CO_2 concentrations in the atmosphere.

	Case A	Case B	Case C
Economic Growth	**High**	**Medium**	**Low (North)** **High (South)**
Technological Progress & Resource Availability	**High**	**Medium**	**Low (Fossil)** **High (Non-Fossil)**
CO_2 Emission Limits	**No**	**No**	**Yes**
Number of Scenarios	**3**	**1**	**2**

Table 1. Characteristics of six scenarios for a global energy future

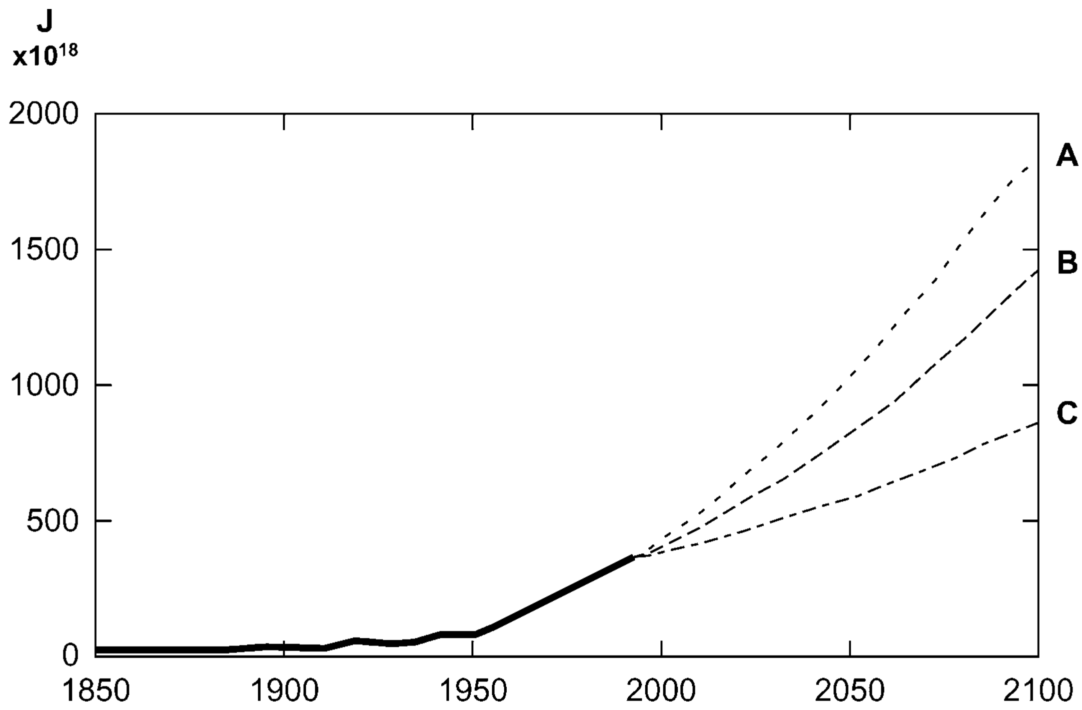

Figure 6. Global Primary Energy Demand to 2100

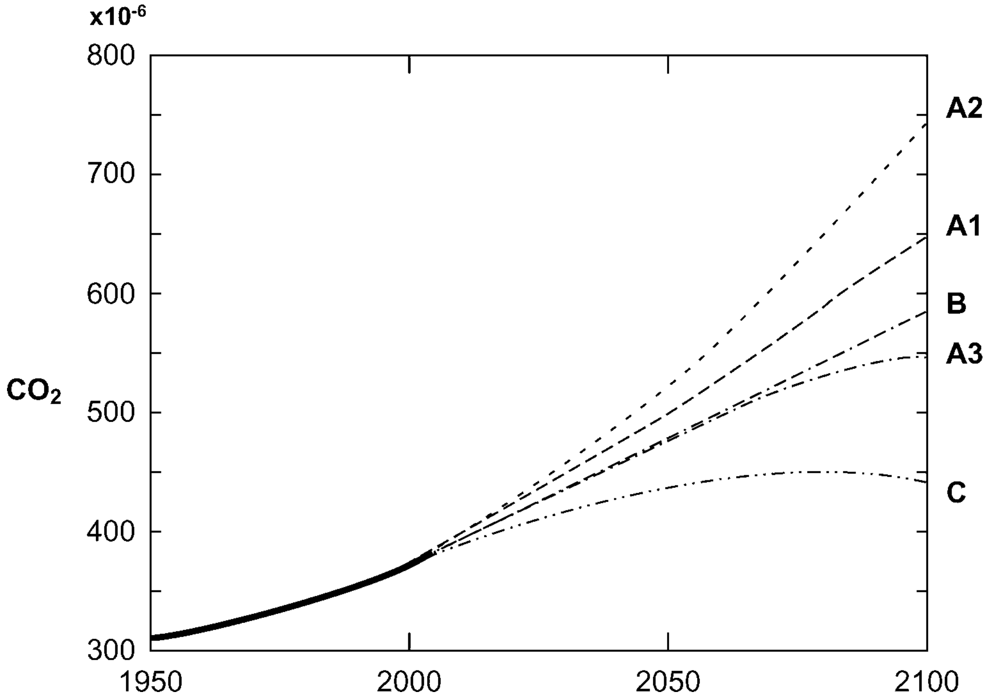

Figure 7. Global CO_2 concentrations to 2100

DISCUSSION

This report presents information on energy and climate issues, collected to form the basis of a discussion on the need for the development of a long-term, sustainable energy strategy for Canada, as well as globally. The draft report was presented to the members of the Academy at the Annual General Meeting in Calgary on June 1, 2001. The discussion by the membership present at the AGM provided valuable input to this chapter of the report.

The need for a sustainable, long-term energy strategy is foremost driven by population growth and growth in GDP. At the same time, the future energy scenarios mentioned earlier in this report which are able to deal with this growth without compromising the needs of future generations, rely heavily on the development of new technologies, or the further development of existing energy related technologies.

The evolution of the world's energy systems over the next century will indeed be affected by many factors, such as:

- changes in the energy supply mix
- the number of vehicles on the road (more than 1 billion by 2020)
- fuel cells replacing internal combustion engines
- the evolution of a bio-based economy
- more efficient conversion of fossil fuels to electricity (decarbonization)

- development of capturing and sequestering CO_2
- more fuel-efficient, new-generation vehicles

The challenge for all of these factors is improved or new technology at a reasonable cost. Some examples of what has already been achieved in recent years would include the following (Ref. 7)

- the cost of wind energy has been reduced by some 30% over the last decade
- the cost of producing ethanol from biomass has been reduced by some 70 % since 1975
- the cost of solar thermal power has been reduced by about 15% over the last decade
- the cost of solar photovoltaic power has been reduced by about 20% over the last two decades

These reductions in cost follow the traditional cost pattern of a new technology. In the R&D stage costs are obviously very high, and not a real factor from an economics point of view. The next stage of a new technology is the demonstration stage, where costs tend to decrease rapidly, allowing for the beginning of the learning or experience stage. Typically, at this stage of the introduction of new technologies, the investment cost falls at a rate of about 20% per doubling of the production of energy. The renewable energy sources (wind power, solar power and biomass) are still at the learning stage with a falling investment cost rate of about 20% per doubling of production. After the learning stage comes the commercial or production stage, where the technology has been accepted in the market place as a viable alternative, not necessarily for economic reasons, but perhaps for social, environmental or safety reasons. During this stage the investment costs can still be expected to fall, but now at a rate of about 10% per doubling of the production. It is through this well-established cost pattern of developing technologies that new technologies can start competing with existing technologies strictly on an economic basis.

An example of a fully developed energy technology now in the commercial stage is the aero-derivative gas turbine. Originally designed as a jet engine for military aircraft, this *new* technology was adapted to an energy production application in the 1950s and became a commercial product in the energy sector around the mid-1960s. Up until then the rate of cost reduction had been about 20% per doubling of production, but changed to the 10% level when the aero-derivative gas turbine became a fully accepted commercial product for energy conversion.

In developing an energy strategy, it is important to know the comparative costs of delivered energy, coming from the different energy source options. These costs will depend on the original investment costs and the operating costs. The following table shows the investment costs, obtained from data collected and averaged by IIASA and WEC, from many installations in many countries (Ref. 7).

Technology	US$ (1990)/kW
Simple cycle gas turbine	250
Wind power	1250
Biomass	1500
Nuclear	2000
Solar thermal	2750
Solar photovoltaic	4250

It is notable that the investment costs of gas turbine engine installations for power generation is still considerably lower than for the renewable technologies, or for nuclear energy.

CONCLUSIONS

Knowing that the global demand for energy will increase by as much as 600% in this century, the required expansion of energy choices is very large indeed. The engineering challenges and the complexities of the technologies necessary to realize a sustainable energy future are immense.

Apart from the technological problems related to a long-term energy strategy, there are many other factors to be considered in the development of any national strategy. One aspect, which was given high priority at the AGM of the Academy, was Canada's sovereignty or independence, given the relatively large role of the US for Canada's energy exports.

Energy can not be adequately treated in isolation. Free trade is probably one of the most important policies to be considered when developing an energy strategy. Perhaps the future fresh water supply issue is another aspect to be considered in the development of an energy policy. Whatever policy will eventually be adopted, it needs to have sufficient flexibility to be able to deal with changing circumstances.

The key focus of a long-term energy strategy has to be sustainability, as defined earlier in this report, but soundly based on an economically responsible policy.

The conclusion of the Working Group is that hydrocarbon-based energy sources should be able to satisfy the six-fold increase in the demand for energy, which is forecast for this century. However, the risk that such a strategy would have significant effects on the climate, and therefore on the global environment, is probably too large to accept.

A long-term, sustainable energy strategy needs to be developed, which will necessarily require a larger choice of energy sources and energy technologies, than presently available. Given the immense challenges of developing energy technologies and the collective expertise of the members of the Canadian Academy of Engineering, it is evident that the Academy can play an important role in the assessment of those already available, as well as entirely new energy technologies.

REFERENCES

1. *Technical Summary of Working Group I*, Intergovernmental Panel on Climate Change (IPCC), 2001

2. *Directory of Members*, Canadian Academy of Engineering, 2001

3. *Energy for Tomorrow's World - Acting Now*, WEC Statement 2000, World Energy Council, 2000

4. Private communication between CAE Working Group on Energy and Climate Change and Global Change Strategies International Inc, 2001

5. *Survey of Energy Resources*, World Energy Council, 1998

6. *Nuclear Sector Focus - A Summary of Energy, Electricity and Nuclear Data*, Atomic Energy of Canada Ltd., 1999

7. *Global Energy Perspectives*, International Institute for Applied Systems Analysis (IIASA) and World Energy Council (WEC), Edited by Nebojsa Nakicenovic, Arnulf Grubler and Alan McDonald, 1998

8. *Canada 2050 - Four Long-Term Scenarios for Canada's Energy System*, Natural Resources Canada, www.nrcan.gc.ca./es/etf

9. *Technology Innovation for Mitigating Greenhouse Gas Emissions*, Foundation Paper of the Technology Table, OERD, NRCan, 1998

APPENDICES:

A. Members of the CAE Working Group

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Joe Ploeg (chair)
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SNC-Lavalin Inc.
Hydro-Quebec
Imperial Oil Limited
Ontario Power Generation
Government of Canada (Climate Change Secretariat)

C. Conversion Table

1 toe (tonne of oil equivalent)	=	42 GJ = 11.67 x 10^3 kWh
1 tce (tonne of coal equivalent)	=	29.3 GJ
1000 m^3 of natural gas	=	36 GJ
1000 kWh	=	3.6 GJ = 0.086 toe

Mega = 10^6
Giga = 10^9
Tera = 10^{12}
Peta = 10^{15}