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Energy Technology Futures 2050

Purpose

This paper outlines four long-term scenarios for Canada's energy system for the 2030-2050 period. These scenarios have been developed by the Office of Energy Technology Futures of Natural Resources Canada (NRCan) over the period from July 1998 to October 1999.

Background

In Kyoto, Japan, in December 1997, Canada joined some 160 nations in agreeing to reduce the build-up of greenhouse gases in the earth's atmosphere. Canada's commitment under the Kyoto Protocol is to reduce our greenhouse gas emissions to six percent below 1990 levels by the period between 2008 and 2012. By that time, Canada will be required to reduce GHG emissions by about 200 megatonnes from current trends.

What are the Greenhouse Gases?

There are six greenhouse gases covered under the Kyoto Protocol - carbon dioxide (CO2), methane, nitrous oxide, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF6).

Of these six gases, three are of primary concern because they are closely associated to human activities.

Carbon dioxide, or CO2, is the most important of the greenhouse gases released by human activities. It is the main contributor to climate change - through the burning of fossil fuels.

Methane is produced naturally when vegetation is burned, digested or rotted without the presence of oxygen. Garbage dumps, rice paddies and grazing cattle, release large amounts of methane.

Nitrous oxide occurs naturally in the environment but human activities are increasing the quantities. Nitrous oxide is released when chemical fertilizer is used in agriculture.

To help Canada meet these commitments the federal government established the Climate Change Action Fund (CCAF). The CCAF is designed to build an overall federal-provincial response to the climate change issue national strategy for meeting our Kyoto commitments. At the federal level, this overall response strategy is being co-ordinated by a Climate Change Secretariat reporting to the Deputy Ministers of Natural Resources Canada and Environment Canada. The Secretariat is responsible for putting in place a co-ordinated federal action plan to respond to the Kyoto challenge and to engage Canadians in longer-term solutions.

The CCAF has four components:

The Public Education and Outreach component supports projects that build public awareness and understanding of climate change and promote actions to reduce greenhouse gas emissions.

The Science, Impacts and Adaptation component supports further research to advance our knowledge of the magnitude, rate and regional distribution of climate change and its impact on Canada so we can better estimate the risks of climate change. It also supports research on adaptation to these changes.

The Technology Early Action Measures component of the CCAF supports cost-effective technology projects that will lead to significant reductions in greenhouse gas emissions.

The Foundation Analysis component supports sound analysis of options to meet Canada's Kyoto commitments. The Energy Technology Futures Project is one of the elements of the Foundation Analysis work, and is the only activity under the CCAF that looks beyond the Kyoto time frame.

Energy Technology Futures

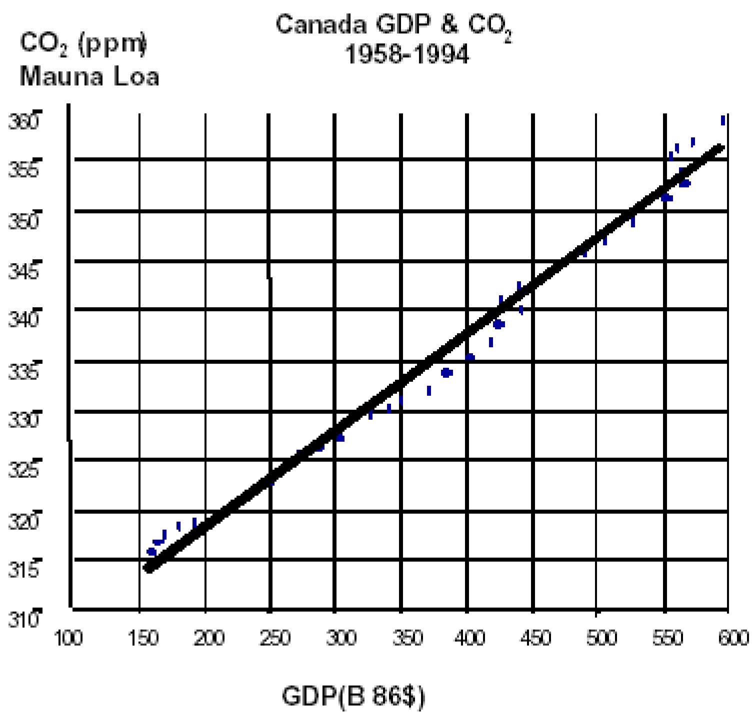
In June 1998 Natural Resources Canada (NRCan), the federal ministry responsible for policies and programs related to the energy, minerals, and forestry sectors as well as the earth science sector initiated work on the Energy Technology Futures project (ETF). The project is a major policy research effort designed to move beyond the current time frame and focus, and develop possible visions of Canada's energy system three to five decades into the future. The project is designed to address the main public policy issue in the climate change debate; i.e., altering the fundamental relationship between economic growth and increasing GHG emissions. The secondary objective of the project is to improve NRCan's longer-term S&T planning capabilities.

ETF considers technologies at the conceptual stage of development (technologies which have not undergone testing nor have moved into the applied stage of the R&D cycle) and at the early prototype stage (technologies that are candidates for commercialisation, but need additional development and testing). This does not mean that technologies identified by other climate change processes (such as TEAM) or existing technologies could not be included in the ETF mix. The difference is that ETF would see these technologies moving from their current status to market implementation so that they are substantive contributors to the overall energy system and GHG emission reductions.

Canadian GDP and GHG Growth

The historical relationship between the growth of GHGs and that of the economy (as measured by GDP) have been virtually linked (Figure 1 [1]). This is not just a Canadian phenomenon, global economic and atmospheric CO2 emission trends exhibit even closer correlation. Altering that relationship implies fundamental changes in how Canada develops and uses its energy resources.

Figure 1



The Approach

The primary product of the ETF project is a set of internally consistent and logical scenarios of Canada's energy system three to five decades into the future. The scenarios are focused on energy sources, energy carriers and energy technologies. They do not focus on policies, regulations or fiscal instruments that could be in place. The scenarios are intended to give a view of what Canada's energy system could look like in 2050. They are intended to stimulate thinking by all stakeholders and help them make plans and decisions with a broader view of the potential role, and limits, of technologies over the longer-term. Each scenario describes a distinct and plausible Canadian "world" in terms of its global context and how Canada fits within that world. Each scenario also discusses the energy system that could be used in Canada for the way we live, work, and move people, goods and resources throughout the economy. Each scenario also provides an estimate of energy demands, fuel mix and GHG emissions.

> The project adopts the notion of energy services, both from a consumer and producer perspective. Consumers do not demand energy but the services it provides; i.e. mobility, space conditioning, illumination, motor drive, etc. How those services are met, either by technology or a form of energy, combine to make an energy system. Thus, what historically has been looked at in a two dimensional context of energy demand and supply, has now to be looked at in at least three dimensions of services, fuels and technologies.

Inputs to the Scenarios

The scenarios have been developed on the basis of the following inputs:

1.0 A Set of Common Assumptions

1.1 Socio-Economic Assumptions

ETF has assumed a stable socio-political future for Canada in all scenarios, in that;

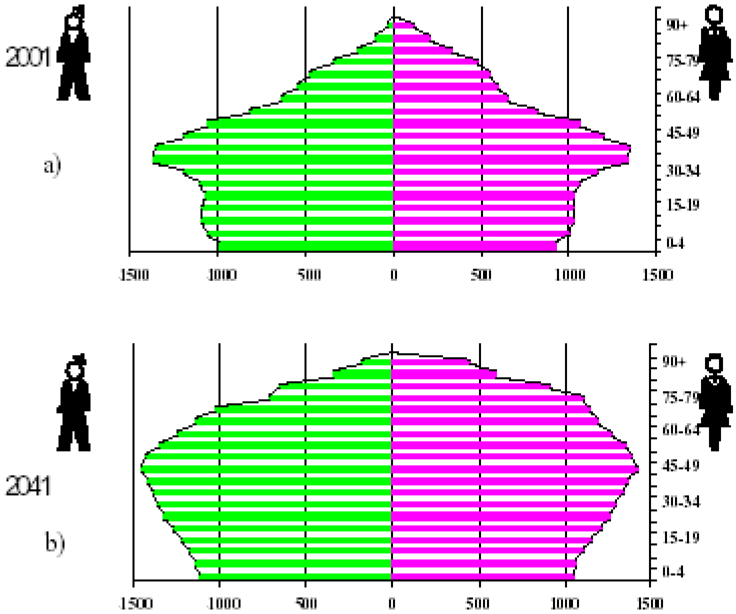
- Climate change will continue to be given a high priority in domestic and international policy for several years to come.
- The range of energy service demands will not significantly alter: i.e. there will still be a requirement for space conditioning, mobility, motor drives, etc.
- Minimal changes in lifestyle will take place over the period to 2050.
- Fundamental political change will not take place.
- Infrastructure will not be replaced until it has served its useful economic life.

1.2 Demographics

ETF obtained projections from Statistics Canada for population and economic growth through the 2020-2041 period and extended these trends to 2050. Based on these estimates, Canada's population will grow from its current level of 31 million to between 35 and 50 million by 2041 depending on immigration levels. The scenarios have been built on the middle range assumption that immigration will continue its current net level of 250,000 per year. In that case Canada's population will be 37 million by 2020 and 43 million by 2041, and 44 million by 2050. That growth rate – approximately 0.7% per year- will be the highest in the developed world.

The ratio of people below the age of 16 and over 65 compared to the population within those years, the 'dependency ratio', will rise from 48% in 2000 to 64% in 2041 primarily because of increases in the elderly population. The population aged 65 and over will double from the current 12% of the population to about 25% by 2041 [2].

Figure 2



The number of households in Canada could reach nearly 21.7 million by 2050 almost double the current number of 11.2 million. One-quarter of these will be maintained by Canadians 55 years or older. More than half of all families (55%) will consist of two persons or less[3].

The urban/rural distribution of Canada's population will be approximately the same. Toronto and several other major cities will double in population by 2041.

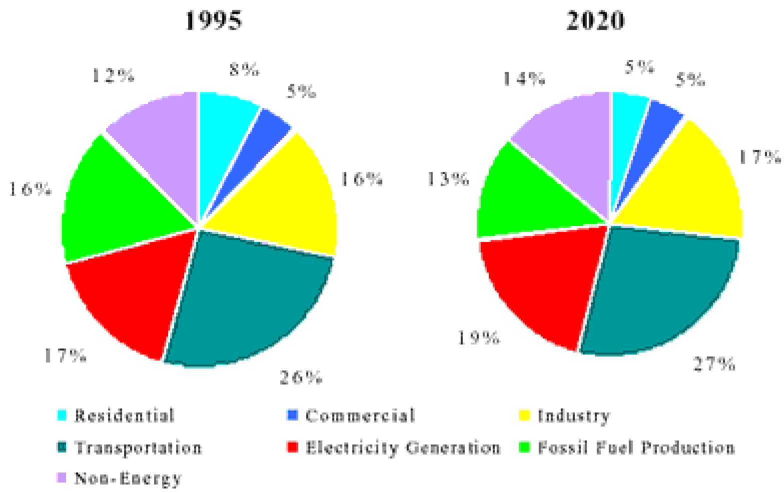
1.3 Economic Growth

An average of the four economic forecasts used by ETF indicates a minimum annual increase in Gross Domestic Product (GDP) of approximately 2% per year through to 2025. Some scenarios assume higher levels of economic growth due to increasingly open global trade and/or pace of innovation.

1.4 GHG Emission Projections for Canada

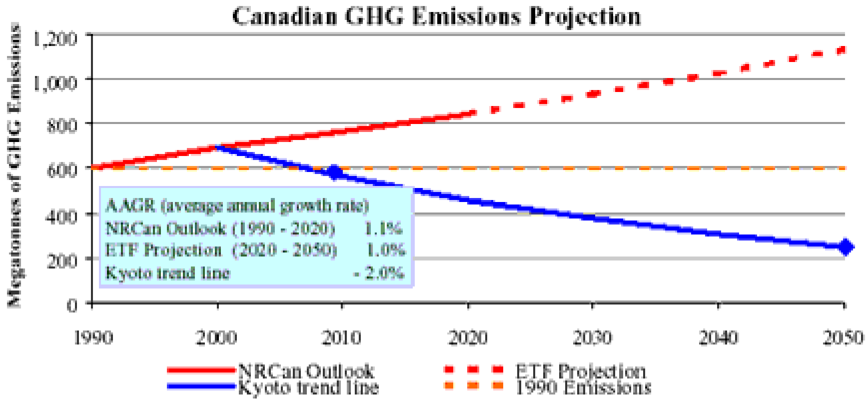
Projections from 2000 to 2020 of emissions of GHGs by source are outlined in Figure 3. Transportation, electricity generation, and industrial energy use account for the bulk of Canada's emissions in that period [4]. Although Canada's energy intensity has decreased slightly since the early 1970s, energy use and GHG emissions have been increasing in tandem with population and economic growth. The emissions intensity of the Canadian economy relative to the GDP will have to decrease by 4.3%[5] annually to achieve the Kyoto target by 2010. This is almost two and a half times the decrease in GHG intensity that occurred during the 1980 to 1990 period when Canada made substantial investments to improve the efficiency of energy use and to encourage shifts away from the use of oil.

Figure 3



To reach the Kyoto target, Canada must reduce its GHG emissions by 2.0% per year from 2000 to 2010. By extending that reduction rate out to the year 2050, we can envisage a GHG 'budget' for Canada in 2050 of approximately 248 megatonnes, as outlined in Figure 4. This is over half 1990's emission level of 601 megatonnes. Conversely, extending NRCan's Energy Outlook line to 2050 results in an emission estimate of just over 1100 megatonnes, almost double 1990 emission levels.

Figure 4



2.0 Technology Perspectives

A set of technology perspectives or outlooks were developed at the beginning of the project to provide a preliminary inventory of technologies currently at the conceptual and prototypical stage. These technologies could be further developed and deployed on a large scale in the market during the 2030 to 2050 period. There are eleven sets of perspectives that are differentiated on the basis of service demands and scientific areas, these include:

- Alternative and renewable energy
- Biotechnologies
- Electricity generation
- Electricity transmission & storage
- GHG management (capture, disposal and re-use)
- Hydrogen
- Illumination
- Mobility
- Process heating
- Space conditioning
- Stationary drives

3.0 Focus Groups and Workshops

From October 1998 to April 1999 a series of international focus groups and workshops were held with representatives from universities, industry, research institutes and government from Canada, the United States, and Europe. The topics covered the full range of service demands, fuel areas and enabling technologies. Each group was provided with the technology perspective(s) for their specific area and asked, with the support of facilitators, to create several speculative visions of the innovation, development, and market penetration of new technologies that Canada could be using by the year 2050. The ETF team developed a report for the results of each session which are available on the ETF web site www.nrcan.gc.ca/es/etf. Approximately 400 experts were involved in these discussions.

4.0 Bi-lateral meetings and laboratory visits.

The ETF team met with approximately twenty individual research organisations, companies and municipal officials to share and compare work and ideas on potential future energy technologies and scenarios.

5.0 Continuing on-line conference via the ETF web-site

The ETF web-site provides all project documentation and a continuous on-line conference. This has enabled individuals to:

- examine the scope, nature, and coverage of the project,
- review and comment on the project products and documentation,
- participate in the on-line conference,
- make suggestions for innovative technologies and their applications.

All contributions have been posted on the site to stimulate further dialogue and debate. To date, the web-site has over 4300 hits and about 200 registered conference members.

Scenario Design

The formulation of the ETF scenarios is built on the work and the assumptions outlined above, but also on scenario planning work of several key individuals and organisations. The ETF Project Team reviewed the various studies; the methodologies employed, and design features of these works. Coupled with the results of the various focus groups and workshops, the team developed a foundation for the design and selection of the set of distinct and plausible scenarios that form the basis of this report.

The scenario design process was as follows:

1 The ETF Planning Space

A planning space, based on three key drivers, created the basis for the ETF scenario design. These drivers were selected after the analysis of issues raised at the various focus groups and workshops, bilateral discussions, and on-line conference. For an issue to be considered as a driver for the project, it had to meet the following criteria:

i) it had to have the potential to lead to significant changes in the future;
ii) it had to be beyond the control of the client group, and
iii) it had to be independent of the other drivers.

The definitions of these drivers and their dimensions or poles are outlined below.

Environmental Etiquette

This vector reflects how business and the public regard environmental issues, and build them into their decision-making processes. This vector also represents a behavioural response to environmental issues, and encompasses environmental ethics and environmental consciousness. It’s polarities range from Grey where business and the public are slow to react to environmental concerns, to Green where business and public demonstrate high levels of awareness and are proactive, incorporating environmental concerns into decisions affecting their operations.

International Markets

The vector reflects the globalisation of the world economy, and the success of market transition and reform. The polarities of this vector are Open where tariffs are dropped, other trade barriers eliminated, the flow of products and capital is unimpeded, and economic integration takes place across all world economies to Closed, a protectionist world, where globalisation has not progressed as anticipated, and countries have a more isolated internal focus on their own economic growth and productivity.

The Rate of Change in the Innovation System [6]

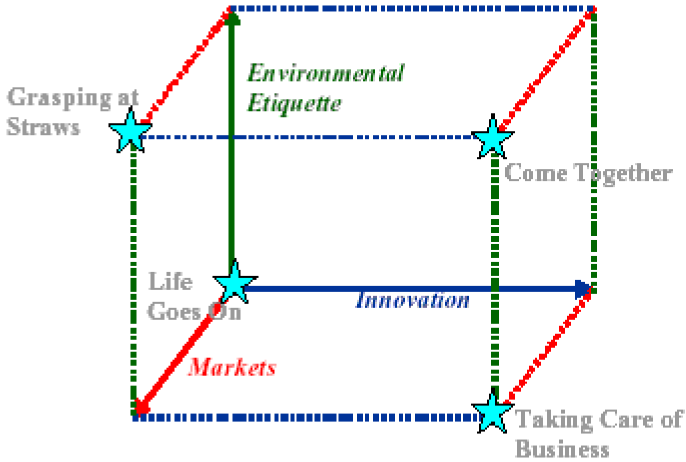
The ‘innovation system’ vector reflects the maturity of the innovation system within Canada. The vector has dimensions ranging from Rapid with exponential growth in new technologies leading to rapid capital stock turnover. Innovation is fostered through education, the effective management of new ideas, concepts and patient R&D, investment leading to product commercialisation. A Slow pace of innovation is one where various components of the chain are not nurtured, and the innovation system evolves at a rate similar to that seen in the late 20th Century. Few players are in a position to invest or exploit the products of that system and the rate of capital stock turnover is slow.

By placing the “low end” of the drivers at the origin, a three dimensional planning ‘box’ was created. The eight corners of the box established the extremes of the planning space and points within the bow box represent the full range of possible world solutions given these drivers.

2 Naming and Selecting the Scenarios

Four alternate futures selected for the project were based on their plausibility and internal consistency and the interest that the scenario would hold for the client group. The four scenarios are also distinct and thus, they can stand on their own. The ETF Team selected and named the following scenarios for further development:

Figure 5



Life Goes On

This is a world with a slow pace of innovation, closed markets and grey environmental etiquette. The various conferences of the parties to the Framework Convention on Climate Change failed to elicit the participation of developing economies. As a result, discussions of environmental issues faded from the international scene. Both developed and developing countries reverted from late 20th Century trade liberation practices and sought greater protectionist policies. Operating in a shell, countries had little incentive to innovate, and environmental issues, while listened to, generally received lip service. Internal political goals of increased standards of living, education, and full employment dominated the agendas of developing countries. While globalisation was a positive goal for these economies the main tenet was that it would be achieved on their terms. Environmentally, this is an increasingly grey world building on existing technologies, with few immediate prospects of becoming greener.

Grasping at Straws

This scenario is one of green environmental etiquette and a slow pace of innovation. It is a world of reasonable economic growth and wide-open global markets. Pressure for immediate action on the climate change issue led governments of developed countries, including Canada, to rapidly deploy a variety of off-the-shelf technologies in the hope of finding a quick fix solution to the climate change issue. The near term advantages of moving mature technologies off the shelf and into the market were well received in this world. Not only did they generate benefits, both economic and environmental, but they also enabled politicians to demonstrate that concrete action was being taken to reduce emissions to both the public and environmental groups. Unfortunately, this focus on deployment and nearer term activities resulted in a very uneven pattern of investment along the innovation chain. The lack of commitment to longer-term planning and far-sighted R&D left countries with limited pools of technologies from which to draw. By about 2030, very few innovative technologies were available to address the climate change issue. This is light to mid green in the near-term, but starts to turn grey as few new technologies are being developed.

Taking Care of Business

Rapid innovation, open markets and low environmental etiquette have led to a world driven by economics and profit. The world is dominated by a system of interconnected transnational companies (TNCs) aimed at furthering their own corporate as well as economic interests. This is a world of rapid capital stock turnover and strong economic interdependence between companies and nations. Expanded economic growth and prosperity has led to a reduced focus on social and environmental issues. It has also led to a growing gap between developed and developing nations. Transnational companies exert not only economic power, but also exert political power in their dealings, particularly with developing economies. This is a world where TNCs locate plants in industrial enclaves within developing countries where reduced costs increase the overall profit base on the TNCs. Available land in these regions was quickly acquired by these TNCs, and in some cases, countries, particularly those with rapid population growth found themselves in a position where rural poverty and worsening urban environments created health as well as social tensions. The international issue in this world is not climate change but wealth distribution. This is a mid-grey world that has turned somewhat greener due to technological advances that have reduced GHG emissions.

Come Together

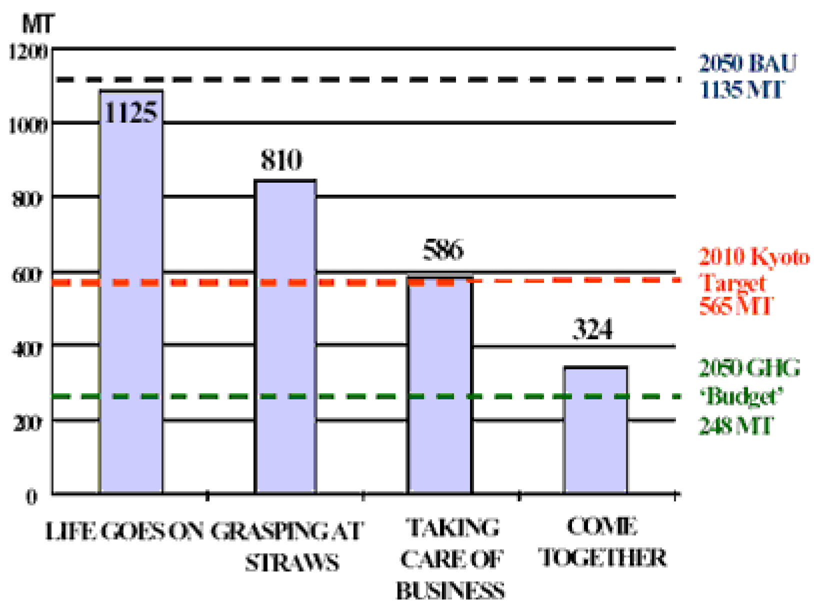
This is a GHG responsive world, with open markets, rapid innovation, and high levels of environmental etiquette. There is a strong cohesion of views amongst government, industry, and the public over environmental issues, and this is shared internationally. Multinational companies exert political as well as economic power, and press governments on environmental, trade and monetary issues. The expanded interconnectedness of the world allows new technology to be openly developed, traded, and applied in innovative ways across all sectors. Canada was well placed in this global market, and Canadian business has been able to capitalise on its expertise and products, and to re-invest in improvements and establish new areas of competence readily demanded in these open and expanding global markets. This world, despite its strong environmental ethic, is mid-green in colour. Reduced GHG emissions realised through technology gains are somewhat offset by expanded industrial operations, extensive international distribution systems, and energy using leisure activities.

Results of the Scenarios

A framework was developed to assess the GHG impacts and implications of each scenario. The framework builds on NRCan's InterFuel Substitution Demand Model that was used in Canada's Energy Outlook 1996-2020 and extended in our estimate of the Business As Usual Forecast.

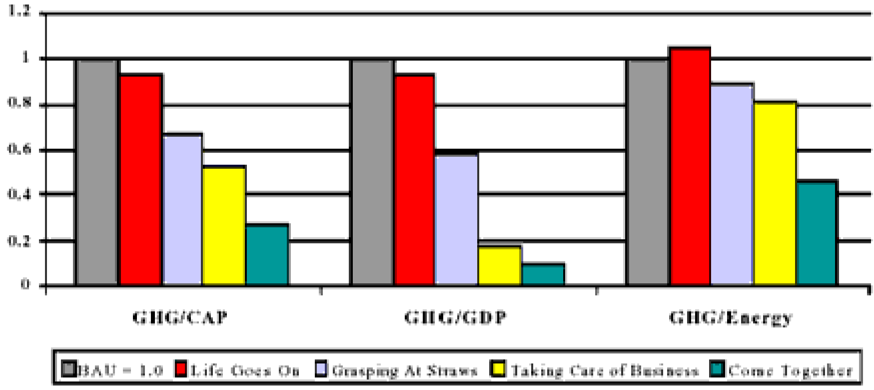
To extend this framework to 2050 three categories of assumptions were used: i) those that related to context assumptions; for example, demographic, and economic trends, ii) those easily calculated from context assumptions, such as vehicle kilometres per capita, and iii) scenario specific assumptions related to efficiencies, technology improvements, and the fuel splits of each scenario. Based on these assumptions, estimates of the GHG emission levels were calculated. The Life Goes On scenario approximates the emission levels in the Business As Usual Forecast. The Come Together scenario has GHG emission levels closest to the 2050 "GHG Budget" for Canada (see Figure 6).

Figure 6



The ETF analytical framework also allows for more detailed calculations to support these levels. For example, Figure 7 outlines the GHG per capita, per unit of output and per unit of primary energy for each scenario. As seen in each case, the GHG per capita is reduced as greater innovation and environmental etiquette are introduced into the scenarios. The carbon intensity per unit of economic output and energy mix also decline. When compared to the Business As Usual Forecast, GHG levels per capita and GHG levels per unit of output lie below it for all the ETF scenarios. Carbon intensity of the energy mix in Life Goes On is above that of the Business As Usual due to a combination of greater reductions in energy use versus marginally lower GHG emissions in the scenario.

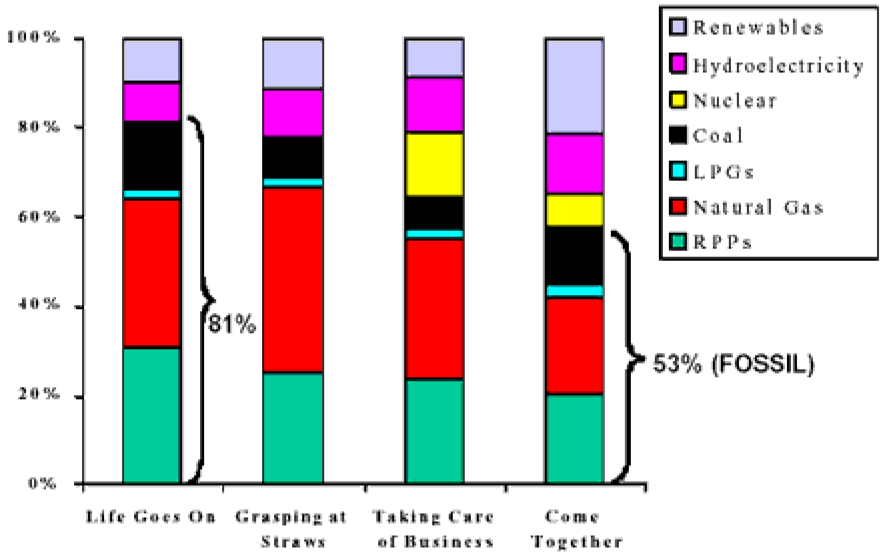
Figure 7



In terms of GHG per unit of output, as the scenarios incorporate more rapid innovation, more fundamental changes in manufacturing systems are seen. In Come Together, for example, these systems are more flexible and agile, and rely on fast re-tooling, multi processing and multi tasking. As well, there is greater use of micro machines, nano-
technologies, and a heavy reliance on high-speed computing. Biotechnologies also play a major role in reducing the carbon intensity of industrial processes in such areas as remediation, separation, purification, and the in-situ processing and upgrading of heavy oil and oilsands. Links between biotechnologies and information technologies have also reduced intensities through such technologies as DNA computing, sensors & controls and artificial intelligence and robotics.

The carbon intensity of the fuel mix is also a major reason for reductions in GHG emissions. Figure 8 shows that then fossil fuel component of the energy mix is declining. Nonetheless Canada still demands and uses fossil fuels. As a proportion of the mix fossil fuels account for about 81% under the Life Goes On scenario (the highest GHG emission scenario) and about 53% under the Come Together scenario (the one approximating the 2050 "GHG Budget").

Figure 8

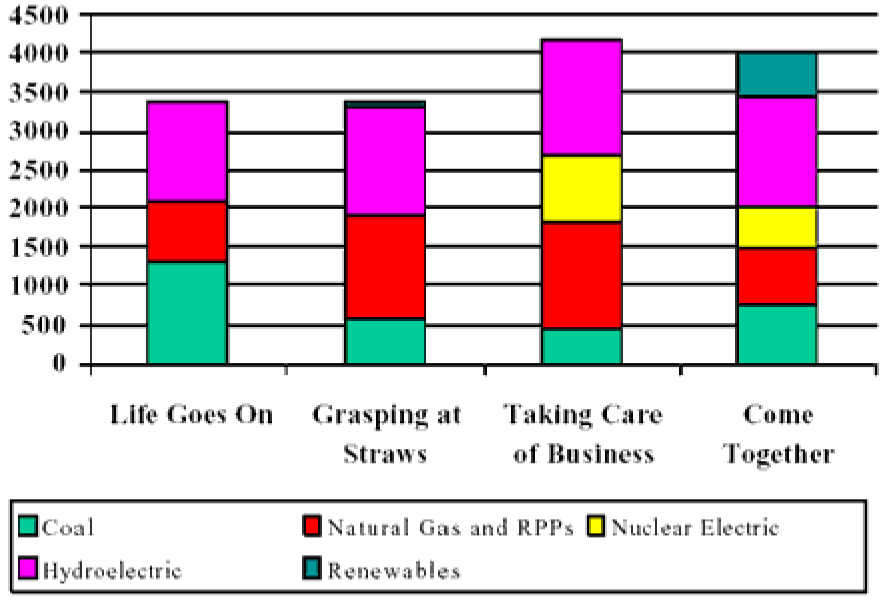


In all scenarios natural gas plays a significant role. As cogeneration systems and combined cycle systems are introduced in Life Goes On and Grasping At Straws, natural gas use increases accordingly. That role does diminish as nuclear is added into the mix under the Taking Care of Business and Come Together Scenarios. For non-generation, natural gas and coal become swing fuels reflecting the interplay of innovation, environmental etiquette, and market access.

Renewable energy sources play a greater role in the mix in Come Together where they account for about 21% of the mix.

Finally, all the various scenarios show greater electrification of the economy. In the analysis of the scenarios the extent of electrification and the shifting nature of the energy sources to meet these electricity needs is identified. Figure 9 shows hydro remaining strong across all scenarios, but that natural gas and coal vary across scenarios in response to the strength of the environmental driver.

Figure 9



Nuclear generation is wound down in the Life Goes On and Grasping At Straws scenarios to reflect the current plant lay-ups, and concerns over waste management issues. In Taking Care of Business and Come Together, nuclear generation emerges as a means of meeting the demands for high quality and reliable power brought about by semi-conductor fabrication, nano-technologies, biotechnologies, and information technologies systems. The availability of modular nuclear units, new reactor designs, and the transmutation of nuclear waste also facilitate the growth in nuclear generation. Super conducting magnetic storage has reduced the needs for peaking power, and allows for more base-load nuclear to be brought on line. In these latter two scenarios there is also a growing reliance on other generation sources including renewables.

Issues and Challenges

Several key issues and challenges emerge for the ETF scenarios. Perhaps the most important are:

i) The Role of Nuclear Energy in Canada

Given the current lay-up of several of its nuclear reactors, will Canada see nuclear generation emerge as a viable source, and will it grow as suggested in some of the ETF scenarios? Will nuclear be combined with hydrogen production and what are the energy and other costs associated with this link? Will Canada redevelop its nuclear capabilities at home or will it rely on units from abroad?

ii) The Role of GHG Capture and Disposal

GHG sequestration technologies can make a significant impact in the overall management of emissions and CO2 in particular. What are the best options for capture, point sources, what about mobile sources such as personal vehicles? Are aquifers or deep ocean options the most effective means to manage GHGs? Can mineralisation of CO2 work effectively?

iii) The Role of Hydrogen

Could Canada move to a hydrogen economy, and if so can some of the issues related to hydrogen (storage, distribution, energy density, consumer acceptance) be resolved and over what time frame? If there is to be a hydrogen economy, how will it be produced, where, and how quickly will it evolve?

iv) The Role of Renewable Energy in Canada

How important will renewable energy sources be in Canada, and how can they be used most effectively and appropriately? Moreover, what will be the effect of other technologies like large-scale electrical storage technologies on renewables: will it help or hinder?

v) Infrastructure Issues

Infrastructure wears out and attention must be paid to the technology, product and plant investment. What are the economic and security implications of infrastructure “rust-out”? How can investment in materials, processes and lifetime assessment techniques allow for better planning?

vi) How do we move from where we are now to where we could be?

This is by far the biggest question arising from the ETF Scenario work. How can the longer-term thinking be built into the policy planning and R&D priority setting activities? What linkages and co-operative mechanisms domestically and internationally are necessary to elicit the changes in the nature of the energy technology and policy activities of countries to realise the key role that technology and innovation have in meeting longer-term environmental and economic objectives? What type of policies, frameworks and conditions are necessary to accelerate innovation and capital stock turnover?

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[1] Hydrogen and Nuclear Energy: Building Non-Carbon Bridges to the Future, Duffey, Hancox, Pendergast and Miller, Atomic Energy of Canada Limited.

[2] Statistics Canada, Catalogue 91-520, Population Projections for Canada, Provinces and Territories 1993- 2016, December, 1994.

[3] Statistics Canada, Projections of Households and Families for Canada, Provinces and Territories, Catalogue 91-522 Occasional, Ottawa, 1995

[4] Natural Resources Canada, Canada’s Energy Outlook 1996 – 2020, April 1997

[5] Natural Resources Canada, Canada’s Emissions Outlook: An Update, December 1999

[6] This definition of the innovation system is clearly distinct from either product innovations that are made by firms in response to competitive forces or from the ability of a firm or economy to employ a technology. The ability of firms to adjust their product design in response to enhanced competition is market dependant, and the use of this definition of product innovation could be linked to market access, and thus these vectors would not be independent.

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