Update

Capturing and Sequestering CO_2

Until recently, it was generally believed that there was no economic method available for the control and management of carbon dioxide arising from the consumption of the fossil fuels. Nevertheless, there are proven technological options that could be employed to capture this gas in many applications. In the production of hydrogen from natural gas, for example, well-established processes have long been used to convert carbon monoxide to hydrogen with steam (the so-called shifting process), with separation of the resulting carbon dioxide from the mixture of gases by physical or chemical extraction techniques. In the case of the emerging integrated-gasification combined-cycle (IGCC) method for the generation of electricity from coal, perhaps as much as 90% of the carbon in the fuel can be separated by adding these extra stages to the process train.

While the additional costs incurred by installing extra steps to capture carbon dioxide are substantial, they are generally less than those incurred in the separation of CO_2 from the dilute flue gas of the conventional combustion process. This is because in the IGCC case, the gas is richer in carbon dioxide content (due to the absence of nitrogen) and because it is pressurized, which facilitates the separation action in physical absorption processes. Report 92, released in December 1990 by the Dutch Ministry of Housing, Physical Planning and Environment (*Technology and Costs of Recovery and Storing Carbon Dioxide from an Integrated-Gasifier, Combined-Cycle Plant* by K. Blok, C.A. Hendriks, and W.C. Turkenburg), stated that the cost of separating about 88% of the carbon in the coal, together with the associated cost of sequestering the captured carbon dioxide in depleted natural gas reservoirs, would add 'less than' 30% to the generation of electricity in IGCC processes in the case of The Netherlands.

A major study of IGCC technology is now underway in western Canada, involving The Coal Association of Canada, TransAlta Utilities, and others. Both Alberta and Saskatchewan rely heavily upon low-cost surface-mined coals of the lower ranks to supply their growing electricity needs. (In the east, New Brunswick Power is also interested in this technology for its projected 230 MWe Grand Lake station.) Since there is an application for the captured carbon dioxide to enhance the recovery of oil (EOR) from some reservoirs in Alberta, in 1990 the Alberta Oil Sands Technology and Research Authority (AOSTRA) accepted a proposal to undertake a study in this field 'to determine the technical and economic feasibility of reducing the rate of growth of carbon dioxide emissions by collecting this gas from major sources and disposing of the collected gas in hydrocarbon-bearing reservoirs where hydrocarbon benefits could be obtained.' Twenty-four companies and government agencies participated in Phase I of this study. Progress on this and other related activities was reviewed at a general meeting and workshop held in Calgary May 27-29, 1991. In the meantime, Imperial Oil Limited has issued a number of valuable documents bearing on this field, entitled respectively *A Discussion Paper on Potential Global Warming* (March 1990); *Response to a Framework for Discussion on the Environment - The Green Plan: A National Challenge* (June 1990); *A Discussion Paper on Global Warming Response Options* (April 1991); and *A Discussion Paper on Air Quality* (April 1991). These papers are available from the company's Environment Department, 111 St. Clair Ave. West, Toronto, Ontario M5W 1K3.

In *A Discussion Paper on Global Warming Response Options* there is reference to a study focusing on carbon dioxide emission sources in Alberta (where there are a number of large coal-fired power generation facilities, oil sands production and refining plants, and other fertilizer and petrochemical plants). The carbon dioxide from these facilities amounts to about 142,000 tonnes per day or about 42% of the Albertan (10% of the Canadian) emissions of this gas. The company estimates it would be technically feasible, over a five to ten year period, to develop the infrastructure to permanently dispose of up to 50,000 tonnes per day of CO_2 amounting to 3.5% of total Canadian emissions. Capital costs would be about \$7.5 billion with annual operating costs of up to \$225 million. When the captured CO_2 is used in enhanced oil recovery, the net cost of disposal would be in the range between \$15 and \$50 per tonne, depending upon the incremental recovery of hydrocarbons achieved, which would offset some of the disposal costs. For the disposal in saline aquifers without a credit from enhanced oil recovery, net disposal costs were placed at between \$35 and \$45 per tonne of CO_2.

In a paper entitled *CO_2 Capture and Use for EOR* presented to the Spring Workshop (jointly sponsored by the Air and Waste Management Association and the Canadian Institute of Energy in Ottawa, May 23, 1991), R.T. Bailey and I.C. Webster of AOSTRA suggested that the financial returns from EOR operations would support a cost of CO_2 of about C\$20 per tonne. These authors also noted a 1983 estimate of extracting CO_2 from the dilute gases of conventional power stations was about \$47 per tonne of $C0_2$ and state that 'the aim is to significantly improve on this cost performance.' One major uncertainty in this field is the extent to which CO_2 remains in the ground after EOR flooding operations: these authors report a wide range of 15-60% in the literature.

It will be very difficult to develop a successful capture and sequestering process to deal with carbon dioxide emissions. Nevertheless, it is necessary to explore all options if in fact it proves necessary to reduce emissions of this gas substantially. Jim Campbell of the Energy Policy Branch of EMR has surveyed the need to evaluate these options in his paper *Technological Options and Policy Choices for Reducing Greenhouse Gas Emissions*, which was presented to a conference dealing with 'Technologies for a Greenhouse Constrained Society' organized by the Oak Ridge National Laboratory June 11-13, 1991. A number of useful graphs were included in this paper which are reproduced here in Figures 1-4. These illustrate historical and projected linkages of emissions with economic parameters. Mr. Campbell states in his conclusion that "a permanent and effective solution to the problem of greenhouse warming is likely to require the development and widespread adoption of revolutionary technologies, which will permit the level of energy consumption society wants, without resulting in unacceptable increases in atmospheric concentrations of carbon dioxide."

In this context, there may well be a place for the capture and sequestering of CO_2. Other possibilities for sequestering of interest to Canada include excavation of large chambers in salt formations, disposal in deep oceans, and injection into some coal beds. The first international conference to examine the whole question of the possibilities for removal of carbon dioxide from the fossil fuels, and its storage, disposal, or possible applications, will be held in Amsterdam March 4-6, 1992. Those interested should contact the organizing committee, whose address is: First International Conference on Carbon Dioxide Removal (ICCDR), P.O. Box 30424, 2500 GK The Hague, The Netherlands.

Japanese Nuclear Program

With all the difficulties that nuclear technology has encountered in the last few years, France and Japan have been among the few countries to maintain aggressive expansion of their nuclear generating capacity. As much as 74.5% of the electricity generated in France in 1990 was from nuclear sources, while in Japan 25.5% came from the 39 nuclear stations in service in fiscal 1989. In comparison, Ontario expects to generate a little over 60% of its energy from its CANDU reactors by 1993.

Japan now plans to generate 43% of its electrical requirements by nuclear means by 2010. This will require the construction of 40 new reactors. Demand for electricity has been growing rapidly — 8.8% in 1990 alone — although the world-wide economic slowdown has now reduced this high rate of growth. Although some other advanced industrialized nations must also import much of their energy requirement (Japan imports some 80% of its total energy needs including virtually all its oil), Japan differs from Europe in that there is no natural gas supply by pipeline. Japan must import all of its requirements in the form of liquified natural gas (LNG) using special tankers. Gas in this form is expensive, but even so, it is the second source of electricity after coal (and ahead of nu-

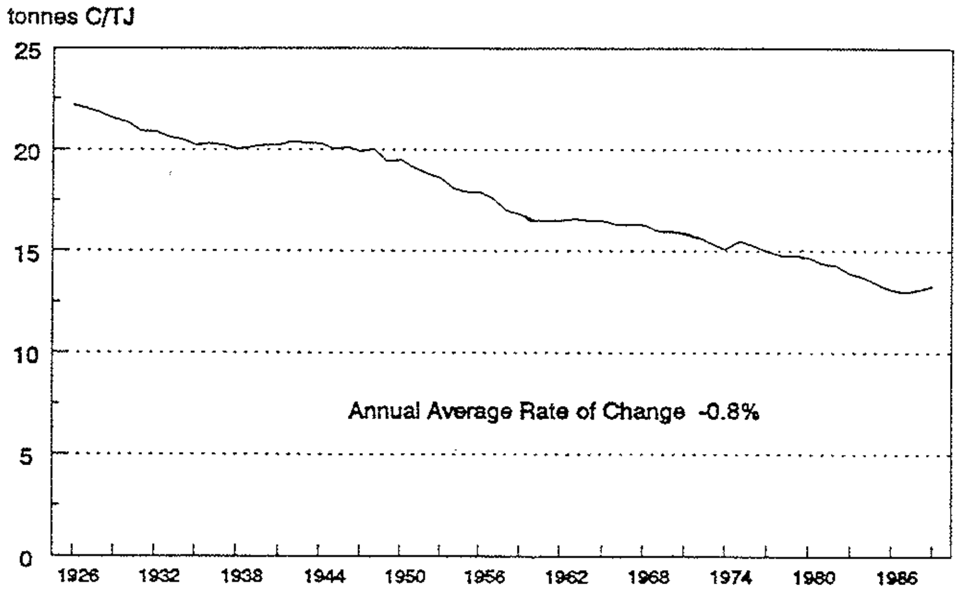

Figure 1: Value of Output per Unit of Carbon Input — Canada 1926 - 1989

Source: J. Campbell, EMR

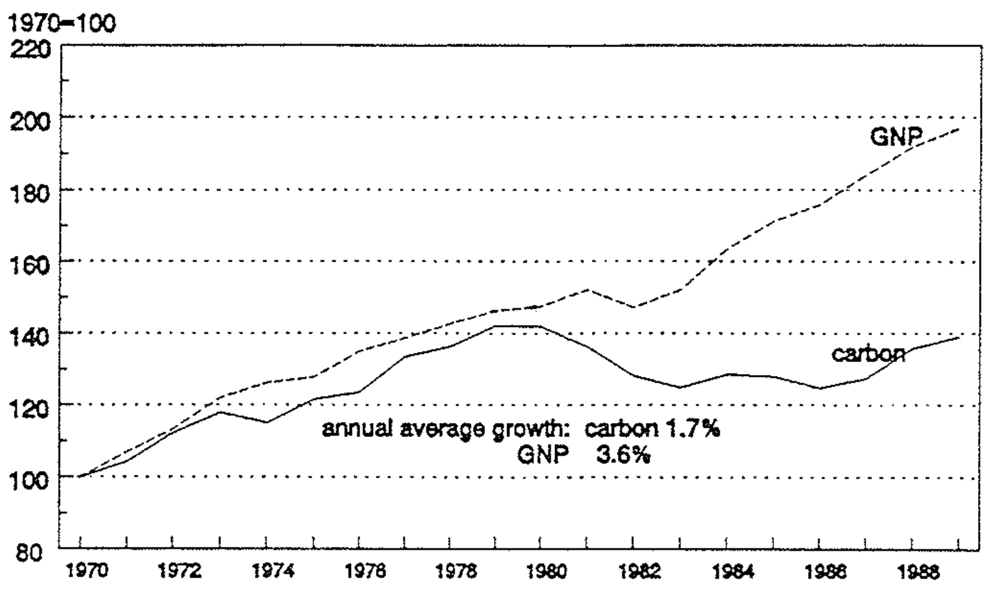

Figure 2: Value of Output per Unit of Carbon Input — Canada 1990 - 2015*

Source: J. Campbell, EMR

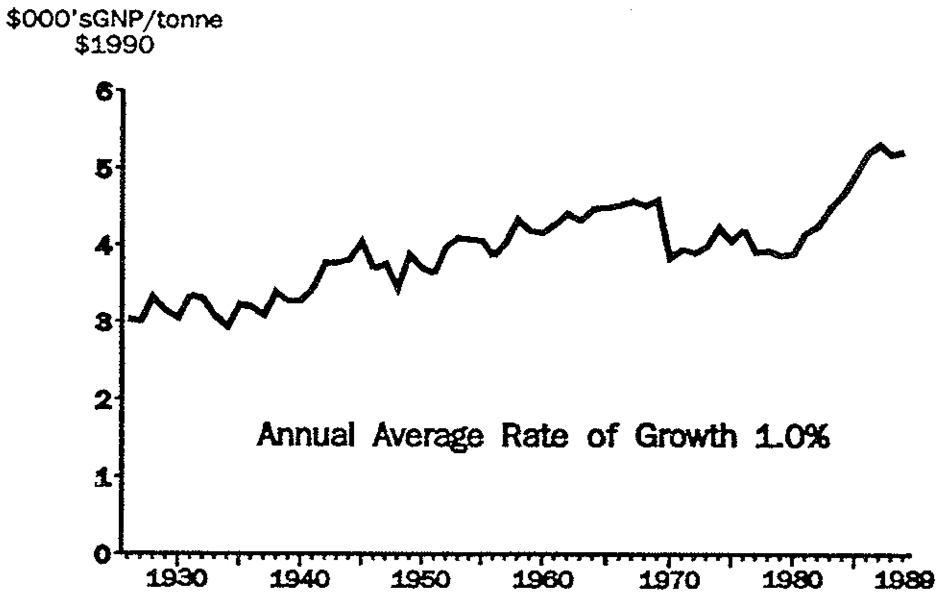

Figure 3: Carbon Intensity of Fuel Use — Canada 1926 - 1989

Source: J. Campbell, EMR

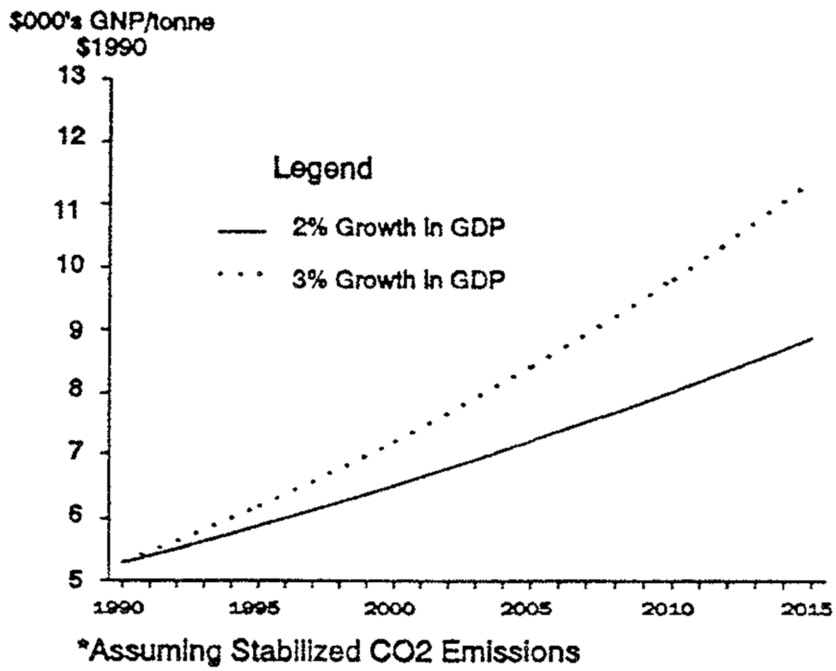

Figure 4: Percentage Change in GNP and Carbon Emissions — Canada 1970 - 1989

Source: J. Campbell, EMR

clear, which now ranks third). Despite its environmental friendliness and research involving new methods of methanol and methane combustion, including recuperative gas turbines based upon imported methanol, natural gas and its derivatives are likely to become less important to Japan in the future.

Aside from a small gas-cooled reactor of British origin, the Japanese nuclear plants are based upon two original designs from the US: the boiling water reactor (BWR) of General Electric and the pressurized water design (PWR) of Westinghouse. Reactors of 1356 MWe capacity are now planned. When completed, Tokyo Electric Power Company's (TEPCO) 8.2 GW Kashiwazaki Kariwa in Niigata Prefecture on the shores of the Japan Sea will be the world's largest reactor (compared with the largest generating station in Canada at 4.1 GW at Nanticoke in Ontario (based upon coal) and the largest nuclear station at Darlington, also in Ontario, which will have a capacity of 3.6 GW when completed). The Ministry of International Trade and Industry (MITI) has recently authorized TEPCO to proceed with an Advanced Boiling Water Reactor (ABWR) of General Electric design which will be simpler and cheaper to build than previous versions of this class. Components will be supplied by Hitachi and Toshiba. Costing about US $1 billion, this new reactor type will be producing 1356 MW(e) by mid-1997.

The Japanese have taken special precautions to protect their reactors against earthquakes. They have also stressed improved operating procedures to reduce the exposure of their nuclear staff to very low levels of radiation. Their practice of offering life-time employment has resulted in a highly-competent work-force with exceptionally high standards of cleanliness. Of late, the Japanese have been focusing on construction practices, and it is now not unusual for a reactor to enter service earlier than planned. Construction modules weighing as much as 400 tonnes are lifted into place by cranes. New technology has also speeded the process of assembling steel reinforcement bars for structures using computer-aided design and robots for pouring concrete.

Since Japan must also import its uranium (it is an important customer of Canada, the largest exporter), it is not surprising that there is work under way to recycle plutonium in fast breeder reactors (a prototype 714 MWth sodium-cooled reactor will begin service in October 1992). Ways are also being sought to use plutonium in advanced light-water reactors. Until the plant at Rokkasho comes on stream to handle 800 tonnes of fuel per year, probably in late 1992, Japan will rely upon commercial re-processing in England and France.

The whole question of re-processing is fraught with difficulties. Major problems have been encountered in finding acceptable ways of transporting the separated plutonium back to Japan. The original scheme to ship by air was opposed by the US, and now an armed escort ship is under construction to guard against terrorist attacks on a transporting ship. Because the reactors (unlike the CANDU) must use enriched uranium, it is also not surprising that an effort is being made to find ways of performing this operation in Japan. A centrifuge process has been developed and laser and chemical processes are being investigated.

In the past year forced shutdowns have occurred in both the BWR and PWR reactors. In one case, a leak in the primary cooling system caused a small release in radioactivity, and in the other, a failure of a hydrostatic bearing, which did much damage to pumps and other equipment, was the cause. Public confidence may have been eroded by these incidents, but on the whole, given the history of Japan, it is surprising there has not been more opposition to this ambitious and vigourous program of expansion of nuclear generation. If France and Japan can demonstrate both a substantial economic benefit from, and safe operation of, nuclear facilities, particularly after the introduction of a new generation of reactor design, the prevailing attitude to nuclear power in other nations, particularly in the US, may well change over the years, especially if the emissions of greenhouse gases from fossil fuels must be reduced.

Source: IEEE 'Spectrum,' April 1991.

Preparation for UN Environment/ Development Conference

The United Nations Conference on Environment and Development (UNCED'92) will be held in Rio de Janeiro, Brazil, June 1-12, 1992, at which time it is hoped that a 'Framework Convention on Climate Change' will be reached. Environment Canada led the preparation of Canada's National Report which was released August 30 (copies are available from The Enquiry Centre, Environment

Canada, Ottawa, Ontario, K1A 0H3; Tel:1(800) 668-6767). Preparatory discussions are being held by the Intergovernmental Negotiating Committee (INC) which held its first meeting in Chantilly, VA (near Washington) last February.

Within the INC, one working group is focusing on broad commitments concerning actions to be taken, and a second group on mechanisms to implement an actual convention. Input to the Canadian position can be made through the Advisory Committee to the Canadian Negotiating Team, and many organizations on the Canadian energy scene are now participating. Thus far it appears, as expected, these negotiations will prove difficult. Many European nations, among them Germany, the Netherlands, and Sweden are pressing for vigourous commitments to aggressive measures to reduce greenhouse gas emissions, while the United States, Japan, and the oil-producing states are counselling caution.

Canada faces a special situation in regard to greenhouse gas emissions. The nation is a net energy exporter in both direct (oil, gas, electricity, and coal) and indirect forms (energy embodied in products — aluminum, pulp and paper, other metals, and so on). There is also significant biomass production, and even greater potential, which may prove to be a very important alternative to fossil fuels. Rather than being lumped into North American or OECD categories, it is essential that Canada gain international recognition for the very different position of its energy economy.

It may be that Canada will find a niche in the international scene by operating energy-intensive industries efficiently and with environmental sensitivity. Should this prove to be the case, Canada would require some form of credit for the energy supplied to other countries in direct and indirect forms, since emissions from Canada would keep increasing. There is need for a more open and informed policy debate as to the appropriate Canadian stance given the Government's announced immediate objective of limiting emissions of greenhouse gases to their 1990 levels by 2000. This goal will be all the harder to meet due to the effect of several factors, especially the severe recession, which lowered 1990 emissions. (See section on NEB Annual Report below.)

BP Statistical Review of World Energy

Every June the British Petroleum Company p.l.c. publishes its invaluable *Statistical Review of World Energy* at its London headquarters. It is the first publication to present the previous year's energy statistics on a self-consistent world basis. The wide acceptance of this statistical source may be judged by the 35,000 copies now printed and that the information can also be obtained in time-series in LOTUS 1-2-3 format stretching back, in most cases, to 1965 on disks for either PCs (5.25 inch) or Apple (3.5 inch) minicomputers. The information is obtained from BP associated companies and other sources compiled in London.

The tabulated data deal with the commercial forms of energy only and is expressed in million tonnes of oil equivalent (MTOE). Primary electricity, i.e., the output from nuclear and hydraulic sources, is reported in terms of the fossil fuel convention and is thus expressed as the quantity of oil required to fuel an oil-fired plant to generate the same amount of electricity. The conversion factor used is 10.5 MJ/kWh, although this is not explicitly stated in the text. The normal alternative to this procedure is to quote the primary electricity in terms of its exact thermodynamic equivalence (3.6 MJ/kWh), a practice followed by the Department of Energy, Mines and Resources and now by the International Energy Agency. Quite different results can be obtained for countries like Canada with appreciable primary electricity production, as can be seen in the accompanying table.

Primary Energy for 1990 Calculated Using Two Different Conventions

	Canada		World	
Conversion Factor (MJ/kWh)	10.5	3.6	10.5	3.6
Total Primary Energy (MTOE)	238.9	186.2	8033.3	7375.0
Shares (%)				
Oil	31.3	40.2	38.6	42.1
Natural Gas	23.0	29.5	21.6	23.6
Coal	12.1	15.5	27.3	29.7
Primary Electricity				
Nuclear	6.9	3.1	5.8	2.1
Hydro	26.7	11.7	6.7	2.5
Total	100.0	100.0	100.0	100.0

Note: Data from *BP Statistical Review of World Energy* for the year 1990 published June 1991.
1 MTOE = 42 petajoules.

Using the fossil fuel equivalence convention (10.5 MJ/kWh), coal, oil, and natural gas supplied 87.5% of the world's commercial energy in 1990. This number rises to 95.3% if the calculations instead use the thermodynamic equivalence method (3.6 MJ/kWh). Which equivalence method is used can significantly alter the relative importance of each primary source of energy.

The difference may be less pronounced for the world as a whole than it is for some smaller regions: fossil fuel and thermodynamic equivalence methods produce minor differences in the data from Alberta, Saskatchewan, and Nova Scotia (which derive most of their electricity from fossil fuels), whereas the two methods produce quite different results for both BC and Quebec (which have large hydroelectric production). The fossil fuel equivalence convention tends to overstate the importance of primary electricity in a country like Canada, but the thermodynamic convention surely understates it because of the high efficiency with which electricity is consumed. Neither approach is entirely satisfactory for all cases.

There are further complications. The World Energy Council chooses to use the fossil fuel convention at a factor of 9.36 MJ/kWh on the grounds that the latter number more accurately reflects average current practice in fossil-fuelled generating stations. The National Energy Board (NEB) inexplicably uses a mixed system: 12.1 MJ/kWh for nuclear-generated electricity (apparently to more accurately represent the actual heat generated in the relatively inefficient nuclear steam cycle), but 3.6 MJ/kWh (the thermodynamic equivalent) for hydropower. In fairness to the NEB, unlike many other sources of such statistics, they warn users of the convention used and offer alternate calculations (if only deep in the appendices of their reports). There is much to ensnare the unwary user of energy statistics.

Other summaries of world energy production and consumption are prepared by the United Nations, the International Energy Agency (IEA/OECD), and by the World Energy Council. In the case of the IEA, the statistics are compiled from submissions of the member nations and from other sources for non-members. The World Energy Council statistics are produced every three years at the time of the regular World Energy Congresses, and are based upon the submissions of individual national committees. The next WEC International Energy Data Report will be issued at the time of the Madrid Congress, September 20-25, 1992. Rarely does this source contain data for the year immediately past. The WEC publications do, however, contain assessments of energy resources in addition to reserves.

It is a monumental task to compile and make sense of the world's enormous energy system, on a self-consistent basis, with its many complex flow patterns. British Petroleum is to be congratulated for this effort. Copies of the *Review* and its companion publications can be obtained from BP Canada or from the London Headquarters (Editor, *BP Statistical Review*, Corporate Communications, Government and Public Affairs, Britannic House, Moor Lane, London EC2Y 9BU, England).

1990 Annual Report of the National Energy Board

The 1990 Annual Report of the National Energy Board was tabled in the House of Commons by the Hon. Jake Epp, Minister of Energy, Mines and Resources, on May 14, 1991. This report provides a useful review of energy activities in Canada and includes the first comprehensive energy statistics for the past year.

Following an increase of 2.3% in 1989, primary domestic energy demand fell 3.4% in 1990 due to lower consumption of natural gas (down 5%), coal (-6%), petroleum products (-2.4%), and renewables (-2.2%), although electrical power use remained stable (nuclear power output fell due to difficulties at some generating stations). Corresponding CO_2 emissions fell 4.0%. The severe economic downturn, higher average temperatures than in 1989, industrial disputes in several major energy-consuming industries, and the escalation of oil prices during the Gulf War contributed to the drop in demand.

Total petroleum export volumes, including exports of crude oil and refined petroleum products, rose by about one-half of one percent. Import volumes fell by 10%. As the price of petroleum exports rose by about 26% while the average import prices rose by only 19%, net petroleum export revenues rose by some 80% to $3.1 billion. Net export volumes of petroleum, expressed in energy terms, rose by nearly 26% to about 800 petajoules. In simple volume terms, however, crude oil and equivalent net exports continued to fall, by some 6.2 m3/d, or 36,000 b/d, last year.

The Board's estimate of remaining established reserves of conventional crude oil increased by 38.4 million m^3, or 6%, compared with the estimate at year-end 1988. Since 1985, annual reserve additions from conventional producing regions have not replaced production and have been progressively declining. However, at year-end 1989, the NEB recognized established reserves for the Hibernia (off-shore Newfoundland), Cohasset and Panuke (off-shore Nova Scotia where production will begin next year), and Bent Horn fields (in the Arctic Islands), and as a result, additions to the reserves of conventional crude oil exceeded production in 1989.

The Annual Report for 1990 is available from the NEB. Those interested should contact the Board at its new Calgary headquarters in the Cadillac Fairview Building, 311 - 6th Avenue S.W., Calgary, Alberta T2P 3H2. (Tel:(403) 292-4800; FAX (403) 292-5503.)

IPL Closes Montreal Extension

At the time of the first oil shock, when six oil refineries were operating in Montreal, (all entirely dependent upon overseas crude), the Federal Government entered into an agreement with the Interprovincial Pipeline Company (IPL) to support the construction of the Sarnia-Montreal pipeline by guaranteeing to offset any financial losses resulting from its operation. From 1976 to 1990, the Government paid more than $150 million in deficiency payments to IPL. For 1991, these payments will be about $11-12 million after taking into account expenses relating to the closure of the line. Over the line's history, throughput has ranged from a start-up of 83,000 b/d in 1976 to a high of 309,000 b/d in both 1979 and 1980. (The design capacity of the line is rated at 340,000 b/d.)

By 1985, only two refineries, with a combined capacity of about 200,000 b/d, were still in operation in Montreal. Furthermore, the increasing competitiveness of mainly North Sea oil meant less demand for Canadian oil. On January 8, 1991 the Minister of Energy, Mines and Resources, the Hon. Jake Epp, asked the National Energy Board to study the implications of the closure of the line. The NEB reviewed submissions by 25 interested parties and reported on April 26, 1991 that security of supply considerations did not justify continued operation. As a consequence, IPL began purging the line and in late June the last oil was delivered to Montreal.

The Montreal extension has been filled with nitrogen to preserve it for reactivation in the future. There is potential for its use in reversed mode to bring off-shore crude to Ontario refiners if demand continues to grow and western Canadian oil production falls as expected. This option will be left to commercial interests in the marketplace.

Progress in the Field of Fuel Cells

In June 1991, the Pacific Gas and Electric Company, the major utility in northern California, started up the first complete power plant based upon a molten carbonate fuel cell. This facility, located in San Ramon, about 65 km east of San Francisco, produces 100 kW from natural gas and cost US $5 million to complete. Funding for this demonstration unit came in part from the Electric Power Research Institute, the US Department of Energy, and the California Energy Commission.

The fuel cell promises to be a clean and efficient source of power. Natural gas is first reformed with steam to form hydrogen, which is the active agent fed to the anode. Air supplies the oxygen consumed at the cathode. The product gases consist of both steam and carbon dioxide, but emissions of this latter greenhouse gas are from 22 to 36% lower than those resulting from other methods of generating electricity from the fossil fuels because the efficiency of conversion in the fuel cell is about 50% higher than in gas turbines.

The next step towards commercialization will be a two megawatt demonstration plant to be built in Santa Clara, California, for operation in 1994. Twenty-four other utilities have expressed interest in this larger unit.

The Fuel Cell Engineering Corporation, a subsidiary of Energy Research Corporation, manufactures the cells for utility use. They project an initial operating span of 40,000 hours, or roughly five years, before they require refurbishing. The company has a cost goal of about US $1000/kW, or $2 million for a two-megawatt plant, which it believes will be competitive with present technologies.

Until now, phosphoric acid fuel cells have been considered the most advanced for utility applications, and such cells have been operating in power plants in Japan for about five years. The carbonate cell, however, offers cost advantages because of its higher capacity per unit of volume. Nevertheless, developmental efforts proceed on several types, including those using solid oxide electrolytes. While these technologies have been known for many years, recent advances in corrosion-resistant metals and ceramic materials, some of which are products of the space program, have made the new fuel cells possible.

In Canada, efforts continue at several universities, developmental companies, and utilities. There is also interest in developing a fuel cell for use on board electric vehicles. For this purpose, Ballard Power Systems of North Vancouver is developing a solid polymer system, based on methanol — a convenient liquid fuel. This cell has been selected by General Motors and the US Energy Department for an electric vehicle development project. Alcan is developing a fuel cell based upon an aluminum-air cell, and a vehicle powered by a rechargeable zinc-air cell system won the First Annual Solar and Electric 500 Auto Race held in April in Phoenix, Arizona.

Assessment of World Oil and Gas Potential

An article in the US journal *Science* evaluates our ability to assess the resource potential for the world's oil and gas. (C.D. Masters, D.H. Root, and E.D. Attanasi, 'Resource Constraints in Petroleum Production Potential,' *Science*, Vol. 253, (July 12, 1991) pp.146-152.) Progress in the geological techniques employed has been such that considerable reliance may now be placed on these assessments for undiscovered petroleum potential.

In the past, assessments of ultimate resource potential tended to increase with time in the light of exploration experience. Now these assessments are stabilizing and, in fact, reductions have been made for some countries, notably the US and Mexico, and for the eastern off-shore region in Canada. (These estimates do not include the very large resources of heavy oil and bitumen found in Canada, Venezuela, and some other countries. In 1990, Canada obtained 12.5% of its oil production from this source.)

The world's original endowment of conventional oil is placed at 2079 billion barrels of which (through 1988) 610 billion barrels (29%) have been produced. Production in 1990 was about 23.7 billion barrels (1.1%). It was stated no new major basins (those with over 20 billion barrels of recoverable oil) are likely to be discovered. Nevertheless, it is the distribution of the resources of conventional oil that leads to the most immediate concern. OPEC producers will be called upon to supply one-half the world's demand for oil as early as 1998 or as late as 2010 depending upon consumption growth and changes in non-OPEC production.

The situation with respect to natural gas derived from conventional sources is, however, more reassuring. The energy equivalent of the world's ultimate natural gas endowment is about equal to that of oil, but production to date has been relatively about half as much. The total world endowment of natural gas was placed at 10,782 trillion cubic feet (TCF) of which only 1523.6 (14%) have been produced through 1988. World production in 1990 was 69 TCF (0.6%). Methanol is now produced from natural gas which may serve as a liquid fuel for vehicles, and it is also possible to produce conventional middle distillates — small facilities have been built in New Zealand, South Africa, and Malaya. The USSR is the world's largest gas producer at 25.7 Tcf in 1990 (37.2% of the world's total production) and there are geological reasons to believe production can be increased markedly in that country. The major difficulty in using the world's large resources of natural gas is to deliver it to markets. It is costly to convert gas to a liquid for tanker shipment as LNG although Japan is a major consumer of gas in this form.

Here, the national assessments of the potential for hydrocarbons are made at the Institute of Sedimentary and Petroleum Geology of the Geological Survey of Canada, located in Calgary. Recent publications of interest include GSC Paper 87-26: *Conventional Oil Resources of Western Canada* by J.A. Podruski et al (1988); GSC Paper 88-19 *Petroleum Resources of the Scotian Shelf* by J.A. Wade et al (1989); and GSC Open File 2150 *Petroleum Resources of the Jeanne d'Arc Basin, Grand Banks of Newfoundland* by G.C. Taylor et al (1991). The US Geological Survey paper lists the conventional oil and gas resources of Canada and the World in this way:

	Oil (10^9 Bbls)		Natural Gas (Tcf)	
	Canada	World	Canada	World
Cumulative Production (through 1988)	14.3	610.1	73.1	1523.6
Identified Reserves	7.0	922.1	94.8	4042.2
Mean Undiscovered Resources	33	547	367	5216
Future Res.	40	1469	462	9258
Ultimate Resources	55	2079	535	10782

Activities at IEA Coal Research Limited

The International Energy Agency (IEA) was established in Paris in

1974 by 21 member and associate nations of the OECD to deal with emerging international energy issues. The importance of enhancing research and development efforts was recognized from the very start of the Agency, including the need for special attention to the potential for coal, the most abundant and widely distributed fossil fuel.

The then-British Coal Board (now British Coal Corporation) agreed to be the Operating Agent to manage coal research through the establishment of a London-based group. Four sub-groups were formed in 1976 to cater to the individual needs of member nations: these were a Technical Information Service, an Economic Assessment Service, a World Coal Resources and Reserves Data Bank Service, and a Mining Technology Clearing House Service. Following an IEA decision in 1982, these services were merged, and in 1986 they become known as IEA Coal Research Limited. The organization now consists of 14 member nations (including Canada), 38 staff members, and an annual budget of Cdn $4 million.

The IEA Coal Research group is the only international research agency in the coal field. The organization acts as a focal point for research activities for this important fossil fuel, and it plays a major role in informing its members as to the technical progress now underway around the world, as well as helping member countries to plan their own programs and avoid unwitting duplication of expensive research efforts. The organization's three basic objectives are to: (1) undertake in-depth studies of technical and economic topics identified by its members as being of special interest to them; (2) create and maintain data bases to which members may refer for information; and (3) provide, through regular publications such as *Coal Abstracts*, *Coal Calendar*, and *Coal Research Projects*, a succinct reference to all significant activities in the field of coal research worldwide.

The work program is divided into: supply, mining and geosciences; transport and markets; coal science; coal utilization; coal and the environment; by-products and waste utilization; information services; and publications. Regular lists of publications and reports are prepared, and a newsletter is distributed three times a year. Reports are sold at special rates to universities and other educational institutions. The large coal data base is now approaching 150,000 items covering the literature from 1978 to the present. It may be accessed on-line through the CAN/OLE and QL systems in Canada, and is now available in CD-ROM format.

Those interested in receiving more information should contact Dr. D.A. Reeve at CANMET, but visitors and short inquiries are welcome at the headquarters in London (IEA Coal Research Ltd., Gemini House, 10-18 Putney Hill, London, SW15 6AA).

Energy and Environment at Royal Institute of International Affairs

The Royal Institute of International Affairs is an independent, self-governing body in the UK which promotes the rigorous and detached study of international questions. The Institute, which was first established in 1920, is located in historic Chatham House, 10 St. James's Square, London, a former residence of three British Prime Ministers. The Institute received its Royal Charter in 1926 charging it with providing and maintaining a 'means of information upon international questions.'

Due to the growing international importance of energy-related environmental matters, an Energy and Environmental Programme was begun in 1987 to move the policy debate on the greenhouse gas problem forward as rapidly as possible into areas which seem to offer the best prospects for agreement among countries, and to point out the implications if no agreement is possible. This focus has been chosen as there seems to be little gained by recommending policies which have only a small chance of acceptance by developed and/or developing countries. The Programme is financed by a number of organizations, both public and private, and the Institute has recently received a substantial bequest from a Canadian, the late Lionel Gelber.

Documents published in this field such as *The Greenhouse Effect: Negotiating Targets* by Michael Grubb (ISBN 0 905031 30 X), *The Greenhouse Effect: Formulating a Convention* by William A. Nitze (ISBN 0 905031 33 4), and *Environmental Issues in Eastern Europe: Setting an Agenda* by Jeremy Russell (ISBN 0 905031 34 2) are available directly from the Institute (£10 each). In 1990, *Volume One: Policy Appraisal* of a two-volume set titled *Energy Policies and the Greenhouse Effect* by Michael Grubb was published (Dartmouth Publishing Company ISBN 1 85521 175 0). In the opinion of this writer, this book of a manageable 294 pages is the best summary of the policy aspects of the subject now published, and should be of interest to all in the energy field concerned with this subject. The second volume, concerned with country studies and technical options, was published in the fall of 1991.

Perhaps the most interesting recommendation made by the Programme authors is a call for a numerical basis of negotiation based upon per capita emissions to be calculated on the fraction of the population aged twenty-one years or older. Other bases commonly mentioned in the literature are equal per capita emissions, equal emissions per unit of wealth created, and equal marginal cost for agreed reductions, although some Japanese authorities suggest inter-generational justice as the main criterion.

Energy R & D Report Prepared for World Energy Council

Nothing has proven more vexatious in the energy field than the planning of energy R & D for the longer term. The technologist looks to the economist for guidance as to what the world will need in the future, while the economist tends to regard technology as a given and contents himself with the question of its application in the most efficient manner. To deal with this impasse, the usual research strategy has been to keep all options open, that is, there has been a tendency to support all possibilities, no matter how remote, at some level at least. As much judgement as possible is brought to bear on the priority setting exercise, but it often becomes one of cutting all proposed expenditures uniformly to make the sleeper fit the bed. At a time when the US dominated the technological field, this strategy was workable if not very satisfactory. With the rise of Japan and other technologically advanced nations, there is now the additional risk of missing a new field entirely — perhaps one of vital importance in the future.

Because of this danger and the difficulties that have been experienced in the past, there are now several efforts underway to find a better approach to this problem. In June 1990, the Chairman of the US Energy Association (the US Member Committee of the World Energy Council) established an Energy Research Committee to reexamine the technology and development programs required in the US with the object of producing a report for the World Energy Congress to be held in 1992 in Spain. The Canadian National Committee (CANWEC) was invited to participate, and Dr. P.J. Dyne, formerly Director of the Office of Energy R & D in the Department of Energy, Mines and Resources, joined this effort. The resulting Discussion Paper, entitled *A Broader View of Energy R & D*, is now available from the CANWEC Office in Ottawa (Suite 305, 130 Albert Street, Ottawa, Ontario, K1P 5G4).

The context for the Discussion Paper was the fundamental changes to be faced by the world over the next one hundred years due to the depletion of current energy resources; the demands and aspirations of growing populations in less developed countries; the increased awareness of the environmental impact of energy supply and use; and the availability of new or improved technologies. The Committee believes that present day R & D activities do not address these needs, stating that there is no comprehensive organized framework for either the allocation of resources for the development of new technologies or for decisions for their deployment after they have been developed. For this reason the main recommendation in the report is for a new approach — the study of the 'architecture of whole energy systems' — which is a break from tradition both in concept and objective. What is required, the Committee believes, is to place the requirements of end-use systems first, allowing them to define the characteristics of the 'architecture' of the supply systems, followed by an identification of all elements of each architecture. These individual elements would then be assessed for resource requirements, environmental impact, and societal implications.

The final step is the 'objective' comparison of the architecture of a whole energy system with other possible architectures. The main benefits of such an approach, in the view of the Committee, will be the provision of a more comprehensive and improved basis for setting priorities for energy R & D programs; improved linkage between the supply technologies and the efficient use of energy; and the provision of a much better basis for communication between the advocates and critics of various approaches to energy questions.

Studies of the R & D needs for the longer term have also been carried out by the International Institute for Systems Analysis (IIASA) in Laxonberg, Austria, and by the Systems Analysis Group of the International Energy Agency R & D Program. Canada participates in both of these activities.

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