THE CARBON DIOXIDE ISSUE

A PERSPECTIVE FOR THE ENERGY RESEARCH LABORATORIES

ERL 90-46 (TR)

16 PP.

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May 1990

Div. Report ERL90-46(TR)

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INTRODUCTION

This document outlines the view of CANMET's Energy Research Laboratories' (ERL) on atmospheric emissions of carbon dioxide. It presents a major revision of ERL's introductory perspective written in early 1989. ERL's responsibilities relate not only to global climate change but also to acid rain and urban and indoor air quality. These factors interact among each other and with other environmental concerns, particularly the management of solid wastes and hazardous materials in land and water. ERL has a critical role in the development of a successful Canadian strategy to manage atmospheric carbon dioxide emissions in a manner compatible with other environmental concerns. This report shows how ERL is meeting the challenge today and discusses what could be achieved through an expanded program.

The principal issue is that the proportion of man-made carbon dioxide in the atmosphere is increasing and that carbon dioxide is a greenhouse gas. While measurements to date of global warming are inconsistent and predictions of future global warming lack precision, there remains the possibility that the greenhouse effect could impact severely on human activity in an irreversible way. ERL bases its perspective on the responsibility of government to define and take the lead in strategies to avoid this possibility.

A closely related issue is that many other man-made pollutants are impacting on the environment. Acid rain, volatile organic compounds and industrial wastes are associated with many of the same human activities as those that cause carbon dioxide emissions. However, some methods of reducing atmospheric emissions of sulphur oxides actually increase emissions of carbon dioxide. ERL's approach is to deal with the many forms of pollution in an integrated and comprehensive manner.

This report covers ERL's mandate to deal with pollutants caused by the production, upgrading and utilization of fuels, concentrating on carbon dioxide emissions. It identifies new and improved fuels utilization and energy conversion technologies. It indicates strategies for implementing these technologies to decrease atmospheric pollution, toxic wastes and carbon dioxide emissions in an economically acceptable way. It explains what ERL has already achieved. And it presents proposals to expand ERL's work to lead Canada in the development of environmentally sound fuel technologies.

Some strategies to control carbon dioxide emissions are deliberately excluded. Strategies not considered include improvement in motor vehicle efficiency and the enhancement of natural biological carbon dioxide absorbers by preserving forests and coral reefs and other crustaceans in oceans. These options, although many of them are aesthetically pleasing, are beyond ERL's mandate.

BACKGROUND

Global Warming

The earth's temperature, specifically the temperature of the biosphere in which we live, is difficult to measure precisely and there are many processes that affect it. Satellites that allow a comprehensive view of the whole planet rather than spot measurements with thermometers may be the best means of measurement. This technology is improving to the extent that reliable measurements of mean surface temperature may be available within ten years. Major causes of temperature change include cyclic variation in solar radiation levels and variation in ocean currents. These processes are complex, interactive and not completely understood. However, one important factor that affects mean surface temperature, the 'greenhouse effect', can be defined clearly.

Radiation from the sun strikes the earth and some is re-radiated at longer infra-red wavelengths. Certain trace gases in the earth's atmosphere, such as CO_2, absorb infra-red radiation and thereby trap part of the earth's heat that would otherwise be radiated into space - hence the term greenhouse effect. This effect is natural, normal and beneficial; without it, the earth would be very cold and life as we know it would not exist. In addition to CO_2, which accounts for half of the effect (49 - 55% according to various sources), infra-red radiation is also absorbed by other gases including methane (18%), nitrous oxide (6%), and several man-made chemicals, such as chlorofluorocarbons (14%). Water vapour is also a very important greenhouse gas, but its influence, especially in the form of clouds, is not understood.

Carbon dioxide build-up

Although mean surface temperature is difficult to measure, the concentration of carbon dioxide in the atmosphere can be measured more precisely. The pre-industrial revolution fraction of carbon dioxide in the atmosphere was less than 250 parts per million (ppm). By the late 1980's this had increased to about 350 ppm at an accelerating rate. The level could exceed 500 ppm by 2050 if the current rate of growth continues.

Canada's contribution to the world's carbon dioxide emissions is large on a *per capita* basis (attributable to level of industrialization, climate and distances) but small as a fraction of the total. The Federal-Provincial-Territorial Task Force on Energy and the Environment reported in April 1990 that the Industrial sector is the major emitter of CO_2 in Canada, followed in decreasing order by the transportation, electricity generation, residential and commercial sectors. This pattern is not expected to change markedly in the near future but the total emissions are forecast to increase by about 25% over the next 15 years.

STRATEGIES TO CONTROL CARBON DIOXIDE EMISSIONS

Natural mechanisms for absorption of carbon dioxide cannot accommodate the effects of human activities, even though man-made emissions are only a small fraction of the whole. The use of fossil fuels is increasing. Both public and scientific perceptions are that there is enough evidence to warrant action. Therefore a strategy needs to be developed to limit CO_2 emissions without damage to the economy.

This strategy must take into account that:

- Fossil fuels will play a significant part in the North American energy picture well into the middle of the next century. It is inconceivable that combustion of oil-derived products could be cut back in a major way in a short time. It is also inconceivable that use of coal to produce electricity, or coal/coke fuels for steel and cement manufacture could be cut back significantly in less than 30 years.

- Massive coal-producing countries (USSR, USA, China) and developing countries (India, Brazil) are increasing their production and use of coal. All developed countries need oil-derived fuels for both transportation and heat. Canada's foreign balance of trade could be enhanced considerably (along with the environment) if we lead and promote the development of new environmentally benign technologies.

- The potential impact of a change in fossil fuel production and distribution on the economy is enormous. Energy may remain an engine of economic growth, but its direction will have to be changed drastically to cut back carbon dioxide emissions.

- New technologies introduced to limit carbon dioxide emissions to the atmosphere must not result in excessive solid or liquid wastes or other environmental damage.

Forcing a significant reduction in global CO_2 emissions would cause enormous economic difficulty because about 90% of the world's primary energy derives from burning fuels that contain carbon. Hydroelectric and nuclear energy sources, which account for nearly 40% of Canada's primary energy, supply only 10% of the rest of the world's energy. And nuclear or hydraulic sources, although they avoid airborne pollutants, are associated with other environmental concerns. Also, the technical, economic, geographic and institutional constraints that restrict the use of these technologies in the transportation and domestic sectors in Canada are often even more severe in other parts of the world.

While slowing the increase in global CO_2 emissions is feasible, the momentum of the growth of fossil fuels in developing countries makes prevention unrealistic, and corrective action will have to be slow if it is to avoid economic disruption. International cooperation is needed and major fuel-using countries will have to expend significant effort. This offers an opportunity for Canadian leadership through example in the international arena.

Means to control carbon dioxide emissions include:

- Reduction of the amount of carbon used as fuel through increasing efficiency of fuel use, switching to a fuel that has a lower carbon content, or decreasing energy demand;

- Capture of carbon dioxide, either in-process during fuel conversion or from flue gases after combustion.

Improving the efficiency of energy use is probably the best way to reduce CO_2 emissions, both from the standpoint of effective management of our energy resources and the dollar savings to the user and the country. It would also make the production of our goods more competitive. It is important to realize that each percentage point of fuel saved through energy efficiency results in a like reduction of CO_2 produced.

Strategies for CO_2 reduction/mitigation can be grouped into five basic categories: specific energy efficiency; integrated energy efficiency; fuel substitution; CO_2 trapping/stripping and disposal; and biomass combustion coupled to reforestation (CO_2 recycling).

Specific Energy Efficiency

This category includes efforts to increase the energy efficiency of specific equipment, such as furnaces, boilers or kilns, by improved combustion, heat transfer or both. It also includes specific processes such as hydrotreating heavy oil wherein greater efficiency leads to energy and CO_2 savings through decreasing the demand for hydrogen made by energy-intensive steam reforming of natural gas. Energy savings and CO_2 reductions of up to 20% can be achieved by improving burner design so that less excess air is required for complete combustion. Existing conventional oil furnaces can by retrofitted with a high pressure-drop flame retention burner head to achieve such savings. Heat exchange improvements in combustion applications can achieve even larger savings. When the latent heat of flue gas is recovered through the use of condensing heat exchangers, CO_2 reductions of up to 37% are possible. Direct firing of fuel into a process, such as into an industrial gas-fired kiln instead of an indirect heat exchange, can yield energy and CO_2 savings of more than 20%.

Integrated Energy Efficiency

A systematic approach to energy use can lead to much greater efficiencies. In addition to improving the efficiency of a specific process, furnace or boiler, the manner in which energy is moved and used can also be improved. Energy systems can be integrated to allow energy to be used more than once; i.e., to allow heat, rejected as waste from one process, to be used directly in another.

In residential or commercial applications, integrating space heating with service water heating into one condensing flue-gas furnace system can generate savings of 46% in both fuel consumed and CO_2 emitted.

A conventional thermal power station burns pulverized coal to produce steam to drive a turbine generator. Electricity is produced at 38% efficiency at best. Energy lost in flue gases is about 15%; the remaining 47% is lost to condenser cooling water. Advanced thermal power processes, such as integrated gasification combined cycle (IGCC) or pressurized fluidized-bed combustion (PFBC) with combined cycle, can improve the efficiency of electricity generation to 45%. This has the potential to reduce CO_2 emissions by 16% for the same power output.

Perhaps the best example of energy integration is a district heating system coupled to an electric utility. Reject heat in the form of hot water can be piped throughout a district to heat individual buildings, especially commercial or industrial, thereby obviating the need for oil or gas furnaces. Cogeneration of heat and power can increase the efficiency of fuel use within that district to as much as 82%. It would also produce 54% less CO_2.

Thermal electric plants (both nuclear and fossil fuel) could beneficially be planned to use combined heat and power in siting considerations which allow effective use of waste heat. Heating loads could be assembled through thermal energy networks. New buildings and central heating networks could be designed to use low temperature hot water rather than steam, as the thermal energy distribution medium. This would improve the efficiency of thermal energy transport, reduce significantly the distribution losses, and extend the distance over which thermal energy can be transported. Modern heat-based chilling technology could be utilized to permit year-round use of industrial or utility waste heat. This strategy would facilitate the operation of combined heating and cooling production plants and lower the need for individual chlorofluorocarbon (CFC)-based air conditioning.

Fuel Substitution

One of the more important chemical parameters applied to fuels, so far as CO_2 generation concerned, is the carbon to hydrogen (C/H) ratio. Complete combustion of a hydrocarbon fuel results in a flue gas composed mostly of CO_2 and H_2O as water vapour. If the objective is to reduce CO_2 emissions, then there are apparent benefits in substituting fuels with lower C/H ratios where it is technically feasible; i.e., move from coal to oil to natural gas. Ideally, hydrogen would be best, but production and handling costs to ensure safety make it too expensive for the immediate future.

There is an important caveat to be applied to fuel substitution. The past twenty years have seen most of Canada's domestic, commercial and institutional space heating fuel switched from oil to natural gas. Older domestic gas furnaces were designed to operate at about 55% efficiency, sometimes lower than the oil furnaces they replaced. Many real estate developers today are still installing inefficient gas furnaces in new houses because of their lower initial cost. A fuel switch from oil to natural gas can result in large efficiency gains and much lower CO_2 emissions only if high efficiency furnaces are installed.

About half of CO_2 emissions in Canada derive from oil, primarily from transportation fuels. A switch from gasoline to methanol for internal combustion engines appears to offer lower CO_2 emissions. However, this is offset by CO_2 emissions and additional energy requirements to produce methanol, as well as by poorer cold weather performance. On the other hand, compressed natural gas requires relatively little processing, produces less total CO_2, and performs well over the wide range of temperatures found in Canada.

Co-firing natural gas with coal in utility boilers, the primary goal being reduction of NO_x emissions, can also produce significant CO_2 reductions. There are many cases where full or partial substitution of one fuel for another can reduce the amount of CO_2 released to the atmosphere.

CO_2 Trapping/Stripping and Disposal

Chemical processes have been developed to absorb or strip CO_2 from process gas streams, the purpose of which is usually to upgrade the gas to a high-value petrochemical feedstock. To apply such techniques to treat flue gas from an electric utility is possible but very expensive, in terms of both money and energy. However, new technologies to produce electricity from coal such as integrated gasification combined cycle (IGCC) could incorporate process steps which would, firstly, increase the CO_2 and H_2 contents of the raw gas (the endothermic water-gas shift reaction), then strip out the CO_2. The product gas would then have a much higher hydrogen content, which when burned in a gas turbine would produce much less CO_2.

The question remains as what to do with the collected CO_2; it cannot be released to the atmosphere. There are a number of possible options. In the prairies, CO_2 can be pumped into heavy oil deposits to enhance oil recovery, or it could be stored in depleted gas reservoirs. Another possibility in the west is to dissolve the CO_2 in underground brine deposits but the problem of chlorine release has not been solved. If the utility is located near an ocean, CO_2 could be liquefied and pumped to the ocean bottom. Ecological effects of disposal have not yet been investigated fully and large-scale CO_2 removal and disposal would be an extremely expensive undertaking. It is not an economically realistic option unless special circumstances offer a market for CO_2 as a chemical feedstock or as a pressurizer and diluent for heavy oil recovery.

Biomass Combustion Coupled to Reforestation (CO_2 Recycling)

Biomass, specifically wood, has a carbon to hydrogen ratio that is slightly higher than oil and triple that of natural gas. Burning wood or wood waste does produce high CO_2 emissions but if the overall or total carbon cycle is considered, a case can be made for biomass combustion that is CO_2 neutral.

Forests, indeed all biomass, release CO_2 into the atmosphere during decay. Burning accelerates this release. However, young forests, where trees are growing rapidly, absorb and fix CO_2 at a rate much higher than older forests with more mature trees. Thus, with proper harvesting techniques as much CO_2 can be captured as that released during combustion. Heat energy is thus obtained with no net production of CO_2.

A large industrial co-generation system is being built in Northern Ontario. Boilers fired by wood waste will supply both heat and electricity to the plant and town. Wood waste is burned anyway (disposal) but soon it will supplant other fuels; a significant reduction in CO_2 production. Forest harvesting and tree planting, coupled to efficient, clean-burning wood combustion systems can be an important means of mitigating CO_2 production.

THE CASE FOR ENERGY EFFICIENCY

To understand the importance of energy conversion efficiency in limiting carbon dioxide emissions it is useful to consider energy balances during the combustion of fossil fuels to produce useful energy. About two thirds of the energy in fossil fuels ends up as waste heat. For example, about 0.36 tonnes of coal are required to generate 1 MWh of electricity, i.e. an energy conversion efficiency of 34%. Burning this amount of medium-sulphur coal causes atmospheric emissions of 1.32 tonnes of carbon dioxide, 4 kg of nitrogen oxides, and 11 kg of sulphur dioxide. Higher efficiency combustion technologies such as pressurized fluid-bed combustion or gasification and combined cycle which can potentially operate at 43% energy conversion, can include sulphur retention and reduce carbon dioxide emissions. Using such technologies, 1 MWh of electricity requires only 0.29 tonnes of coal, producing 1.1 tonnes of carbon dioxide and less than 1kg of sulphur dioxide.

Such an increase in energy conversion efficiency is only a first step. If the remainder of the heat in the coal after electricity generation were used for space heating to a practical extent, say 42% of the energy to electricity, 40% to heating, and 18% to stack and condenser cooling losses, emissions of carbon dioxide could be reduced even more. If the space heating displaced natural gas, the reduction in carbon dioxide emissions would be from 1.6 tonnes (1.32 tonnes from coal and 0.28 tonnes from natural gas) to 1.1 tonnes, a decrease of 31%. If the space heating displaced oil, reduction in carbon dioxide emissions would be 40%.

New technologies, e.g., coal-gasification/fuel-cells and magnetohydrodynamics promise energy to electricity conversion with efficiencies greater than 50%. Some fuel-cell studies claim as much as 60%. To illustrate the importance of increasing efficiency, compare the emissions expected from these new technologies with the typical 34% efficient generator cited above which emits 1.32 tonnes of carbon dioxide per MWh of electricity. A unit with 50% efficiency would emit only 0.91 tonnes of carbon dioxide per MWh: a decrease of 31%, this could be enhanced still further by the utilization of remaining low level heat.

Efficiency of energy utilization is a key to decreasing the atmospheric build-up of carbon dioxide. Improved burners in domestic furnaces, more efficient cars, better house insulation, and the use of solar devices and heat pumps can all contribute. Virtually all of these new techniques bring other advantages such as decreased operating cost, decreased fuel cost, decreased emissions of sulphur and nitrogen, and decreased solid waste.

An integrated national strategy requires involvement of industry at an early planning stage, public support for development of technologies through the high risk phases, particularly where the returns to industry are in environmental rather than economic benefit, and transfer of technology to where it will do the most good.

ERL's CURRENT ENVIRONMENTAL ACTIVITIES:

More emphasis has been placed on energy efficiency in all ERL's activities over the past two years. This has been achieved so far without decreasing the effort on projects to mitigate acid rain and improve urban air quality.

Energy Efficiency and Conservation

ERL is developing more efficient fuel technology for residential, commercial and industrial applications, through better combustion, optimization of operating conditions in fuel recovery and conversion processes, and integration of improvements into new energy systems such as cogeneration and district heating or cooling. The efficient use of fuels lowers operating costs and reduces emissions of pollutants and carbon dioxide.

ERL has developed combined space and water heating systems that offer potential for significant overall fuel savings (decreasing CO_2 emissions) and are more compatible with the energy demands of newer houses. Development of safe venting of combustion equipment to ensure good indoor air quality in airtight houses has resulted in major changes to Canadian building and appliance installation codes and practices. New standards written for the Canadian Standards Association by ERL specify emission levels from appliances for the use of wood-burning appliances in airtight houses.

ERL has a program to develop economic technology for switching from fossil fuels to wood waste and other fuels derived from biomass. This includes the development of retrofit techniques and combustion technology to improve combustion performance of installed units by making them cleaner, safer and more efficient.

Field trials on advanced wood-burning appliances in Whitehorse, Y.T. and the northern U.S.A. showed that new technologies can reduce emissions by 50 to 70% and improve efficiency. Combustion trials using artificial logs in conventional fireplaces showed that they can reduce emissions, including CO_2, significantly. These trials enabled the fuel manufacturer to achieve significant export sales.

Nonazeotropic fluids have been identified to improve heat pump efficiency and to replace chlorofluorocarbons, the principal contributors to ozone depletion in the upper atmosphere and significant contributors to the greenhouse effect.

Ice slurry technology, including the development of friction-reducing additives, is showing high economic feasibility for district cooling applications.

Industrial Combustion

A burner demonstration at Canadian Forces Base Gagetown, N.B. reduced NO_x and SO_x emissions by 50% using eastern Canadian coal. At the same time, an associated reduction of 50% in distillate oil use and an increase in boiler efficiency realized fuel savings of more than \$50K per year and decreased CO_2 emissions by nearly 20%.

A design contract was completed for coal combustion facilities for a thermal power research institute in China. Chinese engineers were trained in the use and maintenance of automated flue gas analytical systems. A very small increase in the efficiency of coal use in China (annual consumption over 900 million tonnes) can have more effect on world-wide CO_2 emissions than any major change in Canadian patterns of fossil fuel utilization.

ERL represents Canada in the 13-country IEA information exchange agreement on atmospheric FBC, providing a valuable source of research information to industry. Mathematical models were developed jointly with private, provincial and federal organizations to clarify the effects of various parameters on acid rain precursors, and to design boilers for optimum performance through the IEA Agreement. In Canada's first demonstration of FBC technology at Summerside, P.E.I., tube erosion and wastage of pressure parts were eliminated by low-cost protective hardware replacing exotic materials.

Electricity Generation Systems

Research work on IGCC to improve energy conversion efficiency has been stepped up. Construction of an entrained bed coal gasification pilot plant was completed. The unit will be used in an industrially supported program to gasify Canadian coals and other nonreactive feedstocks. A hot gas cleanup project has been initiated. A joint project was undertaken with the Canadian Electrical Association to assess the feasibility of clean electricity generation using IGCC and a "Databank of Western Canadian Coals for Gasification" was prepared. This research has two goals: to help industry select and adapt the best technologies for IGCC and to evaluate the gasification potential of coals in Canada.

Collaboration with the Canadian Electrical Association through participation in its Generation R&D subcommittee and funding of some its environmental activities continues to be an important part of ERL's work. This subcommittee has a section devoted to environmental issues including CO_2 emissions.

ERL developed a technique for determining unburned carbon in combustion residues and collaborated with electric utilities to measure N_2O stack emissions at 11 Canadian power stations and study limestone injection to control SO_2 emissions from utility boilers using Alberta subbituminous coal. N_2O emissions were found to be close to the threshold of measurement and not to be a problem. The limestone injection studies were used as a basis for a three-year cooperative research program.

Transportation Fuels

Fuel specifications are being developed to improve urban air quality and reduce acid rain because the fraction of highly aromatic synthetic crudes produced by advanced primary upgrading processes from oil sands and heavy oil will likely increase. For diesel and jet fuels, federal regulations are expected to limit the content of aromatic hydrocarbons which contribute to smog and particulate emissions, and the limit on sulphur content will be lowered from 0.5 to 0.05 wt %. Improved, more energy-efficient and cost-effective refining and separation technologies are being developed at ERL to upgrade these fuels.

SPECIFIC PROPOSED ACTIVITIES:

Advanced Clean Coal Utilization

Innovative combustion processes offer an effective energy option for significant reduction of both CO_2 and acid rain emissions from fossil fuel energy systems. Theoretical considerations indicate that reductions of over 50% in CO_2 and over 90% in acid rain precursors can be achieved by combustion at elevated pressures. These technologies will allow the application of combined thermal generation cycles to obtain 16-18% more electricity generated from a given amount of fuel. Coupled with cogeneration (combined heat and power), overall energy savings and CO_2 reduction can reach 54%. Use of limestone as bed material in fluid-bed combustion can neutralize most of the sulphur, while the combustion process inherently produces low NO_x.

Current combustion research focuses on burning at atmospheric pressure. However, operation at higher pressure could potentially strip out more CO_2 at an early stage rather than attempting a cumbersome scrubbing process in the stack. Care must be taken, however, to ensure that the benefits of CO_2 removal are not outweighed by the energy demands of the concentration/stripping process. As environmental constraints become more severe, pressurized fluid-bed combustion processes will allow lower quality fossil fuels, notably coal and petroleum residues, along with wood and municipal or industrial waste, to meet a major portion of Canada's energy demands, cleanly, economically and efficiently.

Suggestions that CO_2 can be economically removed from stack gases, used in other processes, such as enhanced oil recovery, and eventually disposed of permanently require thorough technical and economic review. This is one aspect of Canadian Coal Association's proposal for demonstration and pioneering of IGCC in which ERL is participating.

Specific Objectives:

ERL will lead and coordinate activities that aim to:

- improve the environmental impact and economics of electricity generation, heating and industrial processes by developing pressurized fluid-bed combustion technologies, through in-house research and co-funded private sector demonstrations.

- enhance the development of an Integrated Gasification Combined Cycle (IGCC) system tailored to Canadian needs, to attain improved efficiency in conversion of fossil energy to electricity with containment of acid rain precursors (SO_x and NO_x). This is to be a joint project with the Coal Association of Canada, the electric utility industry and the provinces.

- explore technologies for removal, containment and disposal of CO_2 (In Canada the only technology that appears to offer any promise at the moment is the use and recycling of CO_2 from power stations to stimulate recovery of heavy oil: this could replace the CO_2 presently pipelined into southern Saskatchewan).

Cooperators:

It is expected that development of advanced clean coal technologies will be largely industry-driven. This program contains both in-house research and jointly-funded projects with provincial research organizations, electric utilities, coal producers and equipment manufacturers. Provincial governments, Environment Canada and Industry, Science and Technology, Canada will cooperate in program management and support.

New Approaches to Energy Systems Technology Development

The prime way to reduce CO_2 emissions is through increases in energy efficiency. In non-hydro electricity generation, 60-70% of the heat is currently wasted. Advanced combined cycles to increase electricity generation, coupled with integrated systems to utilize presently rejected heat, can potentially halve CO_2 emissions. Current approaches to energy use centre on energy balances without serious consideration of the quality of energy used. New approaches, such as availability analysis, could lead to significant improvements in overall efficiencies and diminished environmental impact. Other industrialized nations have begun to adopt similar approaches with impressive results. The result can be widespread application of cogeneration and other means of integrating industrial, municipal and utility systems. Given a modest increase in resources, ERL would be in an excellent position to spearhead a radical reassessment of energy use and technology in the economy as they relate to the environment, productivity and economic development of communities and industry.

An overall objective is to integrate new approaches to energy analysis and technology development into all aspects of energy use, and act as a catalyst for parallel and complementary activities by other levels of government, utilities, industry and universities.

Specific Objectives:

- refinement of analytical approaches that optimize energy efficiency, reflecting minimal 'availability' losses and the most appropriate use of the various qualities of energy available.

- detailed investigation of the synergies possible through cooperative energy services among electrical, gas, oil and thermal energy utilities, including integrated load management. Cogeneration from thermal and nuclear power, as well as power plant siting will be addressed.

- accelerated development of technologies necessary to achieve highly efficient integrated energy cascades, including pressurized combustion combined cycles, cogeneration, fuel cells, heat-based chilling, district energy systems for heating and cooling to facilitate the utilization of 'waste' energy sources, and efficient, long distance thermal transport mechanisms.

- develop and disseminate technology to assemble heating and cooling loads through integrated community energy systems, providing heat sinks for co-generation to maximize CO_2 savings potential.

- optimize use of district and industrial integrated energy systems to facilitate the exploitation of biomass (wood) energy at cost-effective scales which, when coupled to sustainable harvesting and reforestation, leads to net CO_2 reductions from the total energy system.

The program will result in significant reductions in CO_2 and other pollutant emissions, primarily through more productive use of energy. Wastes from fuel use will also be reduced. Energy use and emission reductions of more than 54% can be realized by the application of cogeneration compared to separate electricity production and space heating.

Many technologies associated with these new approaches to energy use in Canada have been considered but not seriously pursued because of low energy prices and perceived institutional barriers to implementation. However, in the last two years, some electric utilities have begun to rethink their approach to energy use, making many new opportunities a real possibility.

Cooperators:

Program concepts have already been discussed with other government departments and levels of government, such as Atomic Energy of Canada Limited, Public Works, the National Research Council, Environment Canada, the Ontario Ministry of Energy and the PEI Energy Corporation. Electric and thermal energy utilities are willing to cooperate technically and financially. There is particular interest in accelerating sustainable energy systems planning for communities in Canada.

Cooperation already exists with a broad range of energy system planners and operators in North America including the US Department of Energy and US National laboratories, notably Oak Ridge and Brookhaven. Joint technology development is conducted through the IEA as are assessments of environmental benefits of district energy systems technology. The increased recognition of the importance of sustainable development will stimulate further cooperative ventures for which EMR proposes to serve as a focal point.

Clean Transportation Fuels

Canada's future fossil fuel resources are predominantly oil sands and heavy oils. The quality of these materials is such that considerable upgrading and refining will be required to meet global environmental targets. Also, Canada has considerable reserves of natural gas. Advantage will be gained by conversion of natural gas to clean-burning, high hydrogen/carbon ratio transportation fuels and fuel additives.

The proposed program will build on current EMR programs that include the development of catalytic processes for refining transportation fuels derived from synthetic crude oil. The new program aims to enhance fuel quality by increasing the hydrogen content to reduce carbon dioxide emissions. Additional research will focus on development of catalytic and separation membrane processes for removal of aromatic, nitrogen and sulphur components that contribute to urban air pollution and acid rain. ERL is also developing catalytic processes to convert natural gas into liquid transportation fuels that will alleviate air pollution.

ERL proposes to minimize fuel components that cause urban pollution, acid rain and global warming through a comprehensive program on transportation fuels derived from Canadian resources, including oil sands and heavy oils. The goal is. This program is designed to significantly increase the efforts to protect both the health of Canadians and the environment from damage caused by emissions from transportation fuels.

Large amounts of spent refinery catalysts pose disposal problems. Regeneration and recycling of these catalysts will mitigate detrimental effects on soil and water qualities due to leaching of heavy metals from this material. This program is consistent with Canada's commitment to reducing the impact of transportation fuel emissions on the environment.

Specific Objectives:

ERL will develop advanced processes for production of environmentally acceptable transportation fuels from Canadian sources. Specific goals are to develop technologies to:

- reduce by two thirds the aromatic hydrocarbons which contribute to smog and particulate emissions from diesel and jet fuels and to remove benzene from gasoline;
- remove the sources of acid rain (sulphur and nitrogen containing compounds) from transportation fuels;
- mitigate global warming by reducing carbon dioxide emissions through fuel quality enhancement;
- develop processes to produce a clean-burning liquid transportation fuel from natural gas;
- develop new processes to regenerate and recycle spent refinery catalysts.

Cooperators:

ERL will cooperate with Canadian industry as represented by industrial associations, such as the Petroleum Association for the Conservation of the Environment (PACE), and with other government departments and federal technology centres such as Environment Canada, Transport Canada, Health and Welfare Canada, and the National Research Council. CANMET will also follow closely the recommendations of the Minister's National Advisory Council to CANMET (MNACC) concerning aspects of fuel quality and the environment. This will be accomplished primarily by addressing differences in transportation fuels derived from Canadian resources.

Resource requirements for proposed activities

The proposals above are incremental to ERL's other activities which, by mandate, are addressed 60% to enhancement of industrial productivity, 30% to environmental and workplace protection, and 10% to policy initiatives. Preliminary estimates indicate that the resources required to implement these proposals would be at least $10M and 10 P-Y's per year. Addition of this suite of programs would change the distribution of ERL's work to about 45% productivity, 45% protection and 10% policy.

SUMMARY

The principal issue is that, since man-made carbon dioxide (CO_2) in the atmosphere is increasing and CO_2 is a greenhouse gas, a strategy is needed to limit CO_2 emissions without economic damage. A closely related issue is that many other man-made pollutants impact on the environment. Acid rain, volatile organic compounds and industrial wastes are associated with many of the human activities that cause CO_2 emissions. ERL proposes to treat these many forms of pollution in an integrated and comprehensive manner.

In Canada, industry is the major emitter of CO_2, followed by the transportation, electricity generation, residential and commercial sectors. Canada's contribution to the world's CO_2 emissions is large on a *per capita* basis but small as a fraction of the total.

Improving efficiency of energy use is probably the best way to reduce CO_2 emissions. A systematic approach to energy use can lead to greater efficiencies. In addition to improving the efficiency of a specific process, furnace or boiler, the manner in which energy is moved and used can also be improved. Energy systems can be integrated to allow heat energy rejected as waste from one process to be used directly in another. Another way to reduce CO_2 emissions is to use fuels with lower carbon to hydrogen ratio. Much of Canadian domestic, commercial and institutional heating fuel demand has already moved in this direction by switching from oil to natural gas.

A case can be made for biomass combustion that is CO_2 neutral. Young trees that are growing rapidly absorb and fix CO_2 at a rate much higher than more mature trees. Thus, with proper harvesting techniques as much CO_2 can be captured as that released during combustion. The heat energy so obtained theoretically involves no net production of CO_2.

Improved furnace efficiency has been ERL's major success to date in lowering CO_2 emissions. Recent developments in energy system management have yet to pay off. The proposed environmentally oriented program includes projects to enhance pressurized fluid-bed combustion and integrated gasification combined cycle systems. The advanced energy systems technology program aims to accelerate development of technologies for highly efficient integrated energy cascades, including cogeneration, district energy systems for heating and cooling, and efficient, long distance thermal transport mechanisms.

ERL's program to develop cleaner transportation fuels will enhance fuel quality by increasing the hydrogen content. This will reduce carbon dioxide emissions. Additional research will focus on removal of aromatic, nitrogen and sulphur components that contribute to urban air pollution and acid rain, also on catalytic processes to convert natural gas into liquid transportation fuels that will alleviate air pollution.

This report identifies ERL's involvement in new and improved fuel utilization and energy conversion technologies. It also indicates strategies for implementating these technologies to decrease atmospheric pollution, toxic wastes and carbon dioxide emissions in an economically acceptable way.

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