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Energy Conservation

by F. H. Knelman

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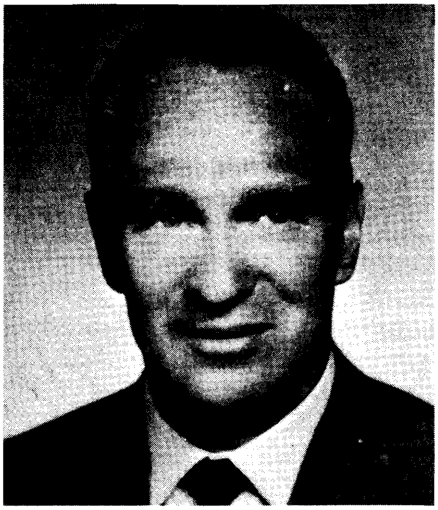

F. H. Knelman

BASc, University of Toronto, 1943; MEng, McGill University, 1950; PhD (Chemical Engineering), University of London, 1953; DIC, Imperial College of Science and Technology, 1953.

Employment:

Dr. Knelman held faculty appointments at McGill and York Universities. He was Foreign Honourary Member of the Mexican Institute of Chemical Engineering in 1971, visiting professor of environmental design at the California Institute of the Arts in Valencia in 1973, and visiting professor in the Technology of Society Series at the University of British Columbia in the fall of 1973. He is currently completing research on Institutional Conflicts in Uranium Miners' Health and Safety for the United Steel Workers' Association. Dr. Knelman is now a Professor, Science and Human Affairs, Concordia University, Montreal.

Publications and Papers:

Dr. Knelman has published many books and articles including *1984 and All That* (Wadsworth, California, 1971) and "The Mechanisms of Bubble Burst", (*Nature,* 1954, vol. 173, p. 261). In 1974 he presented the paper, "The State of Oregon and the State of the World", to the Centre for the Study of Democratic Institutions; the paper, "The Growth of Limits", as a Westwater Lecture at the University of British Columbia; and the paper, "Food and Population", to the national conference of the Canadian Agricultural Chemical Association.

Awards:

Among the awards received by Dr. Knelman is the White Owl Conservation Award in 1972 for Outstanding Canadian Environmentalist of the Year.

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Foreword

This is the first of three background studies to be published to support Science Council Report No. 23, *Canada's Energy Opportunities*. The second of the background studies, "Energy Scenarios for the Future", will be based on some work done by Hedlin Menzies for the Council under contract. The third background study, "Canada's Energy Corridors to the Future", will be a report of the study team that worked under the direction of Dr. G.N. Patterson. These additional background studies will be released just as fast as they can be brought through the final editorial stages.

This Background Study on Energy Conservation was written by the author in part while he was on secondment with the Science Council, in part while he was at Concordia University (Sir George Williams), and in part while on a sabbatical year on the West Coast of the United States. Dr. Knelman brings to this Study his unique experience and talents developed over many years of concern in this area.

It is essential that we start questioning our incessant demand for more energy. The essential portions of our demand must, of course, be met, but what about the rest and how do we separate one from the other? How do we practice conservation and what are the rewards? This is what this Study is all about. Energy Conservation is a tough demanding route, part technical, part economic, part environmental and part institutional. Some will undoubtedly say that many of the conservation activities portrayed in the Study are simplistic and self-evident, but if they are, why have we not addressed ourselves to them long ago? As the Study brings out, the rewards are high.

Many readers may challenge the absolute accuracy of some of the figures or complain that the statistics are incomplete. To them, I reply that this Study is presented with the full knowledge that these challenges will occur, but with the belief that the questions raised will demand continuing research by many, and that the present text will be found a valuable initial contribution and will stimulate many to explore other avenues or go to greater depth in those that have been illumined.

It is our hope that this Study will be the beginning of a major quantitative assessment of energy conservation and will lead to progressive action.

As is the case for all background studies, the opinions expressed are those of the author and not necessarily those of the Science Council, but the connection between Dr. Knelman's Background Study and Science Council Report No. 23 will be evident to all readers.

P.D. McTaggart-Cowan
Executive Director
Science Council of Canada

I. Introduction

An insight into the contemporary energy scene is afforded by studying the historical growth of consumption and production. The daily energy intake, in the form of food required to support human life adequately, is between 2500 and 3000 calories per day (provided it is nutritionally balanced). In pre-history and early history humans lived at or near this energy consumption level. But with the discoveries of fire, domesticated animal energy, and the invention of wind and water devices, the average energy consumption rose rapidly to many times this figure. The Industrial Revolution in the 18th and 19th centuries brought about another great leap in consumption, while today an average U.S. citizen represents the use of over one million calories per day.

Today, the great complex web of industrial processes for the production of goods and services in developed states relies for its power needs on two primary sources, fossil fuels and hydro-electric power. Fossil fuels currently account for over 90 per cent of all energy production in the world. With these fuels, stored chemical energy is transformed into electrical energy or heat energy. The Canadian picture is considerably different since hydro-electricity accounted for 24 per cent of our primary energy consumption in 1972. But this proportion is projected to decrease to 12 per cent by the year 2000.

Behind the essentials of contemporary life in nation states is energy. Food, clothing and shelter, regardless of the stage of economic development, require power for their production. Beyond these essentials, energy still remains the key to industrial growth and economic development.

It is important to clarify the meanings of words – this is especially so for scientific terminology. Energy is the ability or capacity to do work; work is operationally defined as that which is done when a mass is moved by a force; power is the energy consumed per second – each of these terms can in turn be defined operationally.

The basic relationship may be expressed as Power = (Energy)/(Time) and therefore energy is (Power) × (Time). The common units for energy derive from power units (i.e. watt (W), kilowatt (kW), horsepower (550 foot-pounds per second), Btu per hour or calorie per second) and are joule, kilowatt-hour, Btu (British thermal units), calorie or erg.

The fundamental law of energy (Conservation of Energy) implies convertability, the basic conversion then is 1 kwh = 3412 Btu. The Second Law of Thermodynamics, a cornerstone of physics, is equally important. It is significant when one type of energy is transformed to another, for example, when heat is transformed to mechanical energy as in a steam engine. The practical essence of the Second Law is that not all of the heat can be transformed to mechanical energy but some is dissipated, for example, in an internal combustion engine from the hot combustion chamber to heat the cooler surroundings. The percentage of the total heat that can be converted to mechanical energy is a function of the temperature difference. This gives us a quantitative means for measuring efficiency, $E = (T_1 - T_2)/T_2$, where T_1 and T_2 are the temperatures of operation in absolute degrees. The theoretical process is known as the Carnot cycle and provides an insight into the maximum efficiency of a heat engine (40 per cent). On the other hand the reverse transformation, mechanical or electrical energy into heat, is nearly 100 per cent efficient. Physicists thus differentiate between "free energy" like electrical and mechanical and "heat energy" which has limited conversion capacity.

The terms, conservation and efficiency, both seemingly precise in meaning, nevertheless require a more detailed definition. This is particularly true of conservation since there is an implicit latitude for interpretation and an actual spectrum of meaning attached to the concept of conservation. Historically, conservation has been the group of measures adopted to prevent rapid resource depletion and despoliation. In the far past this responsive action has been applied mainly to renewable resources. Ancient Chinese civilizations, recognizing the ecological function of mountain forests, utilized forest inspectors to prevent the denuding of trees from the mountain-side above rivers. It seems quite clear that they saw how such a denuded area not only reduced its own capacity to renew by the effects of rain leaching the unprotected soil, but also contributed to the degeneration of the river. Today we have more detailed and precise insights into the set of intricate and delicate interactions between the use of particular renewable resources such as water and its impact on timber, soil and wildlife. Further to this we have countless more recent examples of the gross impact of the rapid and ruthless exploitation of non-renewable resources such as minerals and fossil fuels on the air, the water and the soil.

Human intervention through the application of new technologies has increased our capacity to affect our environment. The ever-increasing scale and intensity of this intervention now seems capable of threatening the integrity of much larger ecosystems and even some of the great natural bio-geochemical balances. History shows that the downfall of several dead civilizations was the result of the abuse of the land.

We can now begin to understand the scope and meaning of the concept of conservation. The synonym for conservation is not rationing or hoarding in the face of some clear and ultimate limit. Rather the concept of conservation implies the rational management of resources and energy in order to sustain long-term supply while minimizing the negative impacts on the environment and other critical resources. Thus the concept has close links with both ecology and economics since the former deals with the multiple interactions within and between systems and the latter with the allocation of scarce resources.

The word conservation has been attributed to Gifford Pinchot, head of the Inland Waterways Commission set up by President Theodore Roosevelt in 1908. A contemporary definition by Professor Harold M. Rose, of the University of Wisconsin, defines conservation as "the optimum allocation of natural, human and cultural resources in the scheme of national development, whereby maximum economic and social security will be assured."[1]

Efficiency appears to be intrinsically simpler to define than conservation but again definition is difficult. A seemingly simple case of the furnace efficiency of residential space heating illustrates these difficulties. Percentage efficiency is defined as (Energy Output/Energy Input) × 100, but do we confine ourselves to the efficiency of the furnace itself, (and even in this case do we use the lower or higher heating value of the fuel), do we use the actual heat delivered to the rooms as the output, or do we even assign some value for quality, temperature gradients and air freshness of the energy delivered? With inputs, do we use theoretical values or limits against which we measure output? Further to this, how do we measure outputs, in real life situations or under controlled test conditions?

The most useful measure of efficiency, keeping in mind our concern for conservation, would be some form of total system efficiency. The range of total system efficiency for most energy production and application lies between 15 and 50 per cent, except for hydro which is considerably higher. For any use of electricity, if the total system is examined including both generation and application, the efficiency is less than 40 percent. The problem of measuring total system efficiencies for industrial products is very difficult and complex although some bold attempts have been made.[2]

With both conservation and efficiency, care must be taken to consider situations holistically, i.e., as total systems, or we will simply discover that seemingly rational actions on a part of the system will lead to unanticipated and undesirable interactions within the whole system. For example, recycling will conserve materials, but, when *all* the energy inputs are studied, might lead to a greater use of energy. Actually, in most of the case studies, total energy efficiency increases through recycling. If one of the energy inputs such as collection is discounted as a social cost, then the energy balance indicates higher efficiencies. Each specific case must be examined as a total system within other and larger systems in order to judge the net effectiveness of particular conservation and efficiency measures.

Energy Conservation Policy

It is now widely agreed that we are entering a period of global discontinuity or crisis vis-à-vis current dominant energy modes. Most industrialized nations are dependent on oil as their major energy fuel and this dependency is enhanced by many of their major production and service modes, such as petrochemicals, internal combustion transit and space heating. Such dependency will not change for at least the next few

1. Oliver S. Owen, *Natural Resource Conservation*, MacMillan, New York, 1971.
2. Appendix D, no. 5.

decades. The world scramble for oil amidst growing demand projections and political and technological uncertainty of sources only supports this contention of a permanent discontinuity in oil economies. Self-sufficiency has its own problems since it does nothing in itself for global maldistribution and faces the consequences of the tensions produced by such inequity.

There are a number of rationales for a Canadian energy conservation policy. Policy, after all, should not be geared to the present alone but must also be a form of planned adjustment to a developing or projected situation or even a contingency plan for an unexpected disruption in energy supply. It seems obvious that the U.S., for example, lacked energy policies to cope with long-range demand developments and sudden disruptions. Conservation, of course, becomes a necessity rather than an option, in the face of a real gap between energy demand and supply.

While Canadian petroleum reserve figures, as gross quantities, appear to satisfy anticipated demand for about 12 years, we do face an energy development and distribution problem. Quebec and the Maritimes are very similar, in their dependency situation on oil imports, to the countries of Western Europe. Shipments by tanker from the West via Panama are slow and costly. While the large refinery complex in Come-By-Chance, Newfoundland, (100 000 barrels/day) can handle large shipments, it has been financed and designed for Middle East oil for final shipment to the U.S.A. Thus one may argue that Canada faces a regional shortage problem and in the winter of 1974 would have benefitted from an existing conservation and efficiency contingency plan. This could be partially overcome by an extension of the existing pipeline system to Montreal.

Further to this, there is an aspect of overall policy in the resource area that is not confined to the national scene. There is little doubt that even with the most optimistic projections of oil resources, the oil economies of the Western industrialized world are facing a permanent problem of declining supplies in terms of the next two or three decades. Canada's international commitment to increasing development equity should certainly justify a conservation program considering our preferential resource base. The profligate practice of depleting non-renewable resources at the highest possible rate is no longer an acceptable international behaviour. Canada in particular has demonstrated and established its international commitment of global environmental and resource management at the UN Stockholm Conference on the Human Environment. The Man and Resources Conference of the Canadian Council of Resource and Energy Ministers (CCREM) in October 1973 confirmed that a conservation ethic needs to be accepted as both a national and international goal.

Finally, energy conservation can also satisfy national economic goals in view of the high rate of value appreciation of fossil fuel resources. The projected demand for petrochemicals confirms this to an even greater degree. Conservation is thus analagous to sound investment in that the rate of value appreciation for energy fuels, particularly oil, is very high. We are emphasizing oil because at present this is the energy fuel in critical supply and yet its use in the world is projected to higher proportions of primary energy consumption in the future. This conservation policy should, of course, remain flexible and respond to resource substitutions.

Accepting conservation as a sound and desirable policy, the issue then becomes the establishment of a program whose planned measures minimize social costs, social inequities and economic disruptions. To conserve, without at the same time planning to reduce the impact of such social and economic disruptions and inequities, would not be sound policy. In all possible cases prior cost-benefit analyses of particular conservation measures should be made within a general policy framework that enables judgements of short- and long-term effectiveness. But such analyses must also have a human parameter. Aggregate accounting will not reveal regional and localized inequities. Policy must include the minimization of these inadequacies. In terms of increased efficiency measures, the key concept is optimization, not maximization. Thus one must start with the recognition that there is a cost of conservation and efficiency, as there is a cost of growth and inefficiency.

A General Cost-Benefit Analysis of Conservation

Every social choice that involves resources and the environment, also involves costs and benefits. Moreover, under certain circumstances, sometimes known but often unanticipated, the net cost effectiveness may be negative or positive and the sign may vary in time. The difficulties in making sound analyses are well established, i.e., the problem of dealing with the whole system, of understanding interactions and multiple order effects, the problem of quantifying and equating social costs and benefits, and the choice of the time scale for such accounting to apply. All these difficulties are compounded by two powerful, related social processes. These are the institutional nature of economics to maximize short-term returns, and the general anti-planning nature of our economic system. Understanding these mechanisms does not of itself lead to meaningful change. Nevertheless the experience of the U.S. and Western Europe in the face of present energy shortages can only confirm the need for both planning in general and long-range planning. There is reciprocal benefit since it is recognized that localized disruptions often affect the whole economic and social system. The energy crisis in the U.S. has exhibited such interacting and multiple order effects. The selective dislocation and disruption of particular industrial groups, for example, certain sections of the auto industry or industries dependent on key end products derived from petrochemicals affected the support and ancillary industry and service groups of the auto industry. Inadequate oil supply led directly to 250 000 unemployed. This should indicate the advantage of providing time to develop a rational, integrated, anticipatory policy which minimizes such radical social disruptions. In fact, the U.S. crisis is an excellent example of the lack of a sound conservation policy, as they now realize. Moreover, the conservation response in the U.S. itself has its social costs. Cost-benefit analyses must be attempted to justify a particular conservation measure. Even something as seemingly innocuous as car pooling will impact on auto industry revenues. Thus the benefits of car pooling, such as decreased fuel demand, reduction in air and noise pollution, improvement of traffic density, and savings of the order of 30 per cent of out-of-pocket costs of running a standard automobile, must be weighed against the disbenefits incurred.

Minimization of the social and economic costs of conservation requires extensive detailed planning. While we have accepted the long-run flexibility of economic history to sustain the shock of radical technological conversions we have not considered the potential minimizing of such shocks through planning. In particular, conservation proposals with anticipated localized costs have been, understandably, opposed by specific groups who suffer. The case of recycling illustrates these problems. To a large degree labour has protested large-scale beverage container recycling. They have argued that a program of recycling or mandatory returnables will result in a reduced activity in the container production industry with ensuing unemployment. This industry, it would appear, will be made to bear the social and economic burden for this aspect of an energy conservation program. The same argument has been made by transportation services with lower passenger or freight energy efficiencies where plans exist for a modal transfer to transportation systems of higher efficiency. Any group that is made to selectively bear the cost of such production or service mode changes in the name of energy conservation will predictably protest. They will do so despite the ultimate collective benefit of higher rational energy efficiency in a period of rising energy costs and lowered supplies.

Specifically dealing with the beverage container issue, it has been indicated in a penetrating study[3] that total conversion in the U.S. to returnables will ultimately lead to a saving of about ⅔ of present energy consumption by disposables. But, and this is possibly an unexpected result of this study, it will also yield a net increase of 186 000 new jobs! Thus the notion that energy saving conversions automatically lead to reduced employment are obviously simplistic. Nevertheless, a problem remains even in this case of a shift to returnables; without planning, a large-scale decision to convert from disposables to returnables, while having net long-run benefits, will cause a dislocation of a particular segment of capital and labour. However, by staging and planning such a conversion in advance using existing and innovative social techniques for relocating, retraining and reabsorbing labour, the disruption can be minimized. Thus a national energy conservation policy should include

3. Bruce Hannon, *Options for Energy Conservation*, Document No. 79, Center for Advanced Computations, University of Illinois, Urbana, Ill., February 1973.

planning to protect selective groups from bearing the major burden of dislocations. If such a national policy is developed in consultation with all possible concerned groups, including the public at large, and is supported by major educational and informational programs, costs can be minimized and benefits maximized.

There are already in existence institutions in Canada that can ease the severity of dislocations arising from particular conservation measures. Unemployment insurance, labour markets, retraining programs, regional development and redevelopment, or labour information services could well provide a base which, if expanded, could ease any possible disruption of conservation. The manner in which war and peace economies have converted rapidly and efficiently to the other indicates the potential flexibility when supported by planning and motivated by emergency. Nevertheless, it must be admitted that certain kinds of crises, such as sudden resource embargoes or major strikes, do have profound economic consequences and it is never possible to have perfect planning. Even in crises, the existence of contingency plans can have a substantial ameliorative effect. The case of planned conservation through higher efficiency deserves special attention since it can involve a high net cost-effectiveness.

Economists often argue that an absolute reduction in the amount of a resource used at a given productivity and efficiency level will decrease the number and increase the cost of the total goods and services produced. However, if there is a net reduction in energy due to increased efficiency, the same quantity and price of goods and services can be generated. If one adds to this the techniques of increased labour intensity and a shift to higher service functions rather than goods production, employment reduction can be avoided by energy conservation achieved through higher efficiency. There is a real trend toward a service economy already fully developed in the U.S. Surprisingly, in 1970 the U.S. steel and automobile industry accounted for 2.5 per cent of the total employment and all workers in energy intensive and energy producing industries amounted to only 6 per cent of total employment. On the other hand, the personal services sector accounted for more than 30 per cent of total employment. While the figures are different in Canada the trend is similar. In fact, Canada has a higher per cent employed in the service sector.

The automobile industry in North America has been affected seriously by the energy shortage. While this is a result of some unanticipated developments it is mainly a failure of planning and proper projection. Demand for compacts and subcompacts is still increasing. It is inescapable that lowered energy consumption or higher energy costs will not only reduce passenger automobile production but will have second, third and higher order effects on related production and service industries such as parts and gasoline stations. The point is that benefits – lower social costs and the bequeathing of larger stocks for the future – should be compared not only to direct costs – reduced total employment or employment distribution shifts – but to costs offset by switching to more labour intensive production methods and more service (low energy consuming) industries.

A sound energy policy would be characterized by high flexibility whereby a slow, gradual and controlled pattern of management effectiveness and technological and social adjustments to lower energy consumption could be achieved. The ensuing structural changes could absorb the sharp discontinuities normally arising from crisis response. Thus conservation as a policy, to be justified, must produce more gains than losses or at least balance. The public at large should accept as a social cost the dislocation, retraining and transfer of labour affected, if necessary in the form of direct payments for the costs of such structural changes.

Having discussed some of the costs of conservation it is only proper for a balanced perspective to examine the benefits. Some of these benefits are derivative or ancillary rather than direct. Some are only realized in the long rather than the short term, but all are realizable well within the overall time horizon adopted in this study. Since benefits are complex and numerous there will be no attempt to categorize them on the basis of time or derivation nor to elaborate mechanisms of realization. They will be under a series of general categories, i.e., on the basis of their impacts on the following areas:

1. Economics
2. Employment
3. Environment
4. Society
5. Policy Making.

The general major function of conservation is to extend the lifetimes or decrease the rate of depletion of critical resources threatened with serious supply disruption regardless of cause. This extension of time then allows for a more orderly transfer or substitution to other technologies or resources or to the development of new supply sources, all of which require long lead times during which shortages can cause critical social and economic disruptions. Within this overall view, the following are some of the benefits applied to specific areas.

Economics

There are several economic benefits, one of which is the fact that the dollar value of fossil fuels is appreciating and the quantity saved by the end of each term will have an appreciated value compared to that at the beginning of the term. One would, of course, have to subtract the loss due to inflation, but expected price rises of oil and gas would indicate a net appreciation in real value over the next 5 to 25 years. The dramatic rise in the price of oil since 1973 only confirms the high appreciation value of the oil left in the ground. Also, since rapidly rising energy costs are a factor in creating inflation, a lower level of consumption reduces living costs for the individual consumers.

Reducing energy consumption in Canada through conservation and efficiency would reduce or postpone the huge proposed capital investments in frontier resources. This, in turn, would have multiple economic, social and environmental advantages. Moreover, a reduced reliance on the importation of foreign capital would allow increased Canadian control of its resources. An estimate of the reduced foreign capital investment in Canada by 1995 is about $40 billion (Ford Foundation Preliminary Report, Appendix D, no. 9). This Report also concludes that a 50 per cent reduction in energy growth can be achieved with only a 0.2 per cent inflation growth per year and a net increase in employment by the year 2000.

Employment

There is little Canadian data to judge the short- or long-term effects of energy conservation on employment. However a variety of U.S. studies allow us to draw tentative conclusions that a decrease in the rate of energy consumption in Canada is unlikely to affect large numbers of jobs, particularly in the early phases. Sometimes the reverse is true and energy consumption increases reflect energy-intensive substitutions and actually lead to a decrease in employment. This is true for a number of industries where the costs of energy in production are small compared to the costs of labour. Bruce Hannon of the Centre for Advanced Computation at the University of Illinois[4] concludes from his studies that new investment in less-energy-intensive activities would produce a large increase in employment and a small increase in energy consumption. Dairy production, hotels, increased bus and rail transit rather than passenger cars, and hospitals are in this category. Hannon's detailed Dollar, Energy and Labour impact studies (DEL) are very valuable. Obviously a shift to a service economy is a general example of this trend. In particular recycling is both energy-conserving and labour-intensive. Marquis Seidel, Senior Economist in the U.S. Office of Energy Conservation and Environment[5] has suggested that $300 billion may be invested by 1985 in energy conservation measures in all sectors, a third by industry alone. He also suggests that this huge investment spells jobs, mainly community jobs requiring lower skill levels than the employment of professionals in energy production.

Environment

There are environmental costs associated with energy production, transmission and consumption. Some of these have been quantified while others remain unmeasured. Both the U.S. Environmental Protection Agency (EPA) and the U.S. Public Health Service have made such quantifications. A cost of pollution for the pollutant sulphur dioxide has been more thoroughly investigated than most other pollutants, in large part because of its known deleterious effects. This is an environmental damage cost.

4. Bruce Hannon, "Options for Energy Conservation", *Technology Review*, February 1974.

5. Marquis R. Seidel, "Optimistic Economics of Conservation", World Future Society Energy Forum, Washington, D.C., April 24 to 26, 1974.

An Energy Policy for Canada[6] provides a basis for estimating environmental protection costs, i.e., the cost of achieving and maintaining environmental quality while meeting the anticipated production and consumption of energy in the period considered in various sectors. According to the data in Table 1 (p. 171 of Volume 2), we will experience the following costs by 1983 (i.e., at the end of the mid term): in Transportation, $5.5 billion (b); Thermal Generation, $1.8b; other sectors, $1.2b; or a total cost of $8.5b over 10 years for an average population of 25 million. Assuming that our energy savings by 1985 are 10 per cent and that this applies for the total energy projected, then our dollar savings on environmental protection are 0.10 × 8.5 or $850 million which amounts to about $34 per person for 1985. Applying the savings on the basis of each sector separately yields a higher figure of about $75 per person. Revised figures published by Environment Canada are much higher.[7] Using these data, the total pollution control costs for the year 1980 alone are almost $6 billion. The figure commonly used in the U.S. for the cost of air pollution damage based only on sulphur dioxide is $40 per person per year of which 50 per cent is derived from thermal generation. For both space heating and thermal generation a 15 per cent decrease in energy use and production leads to an accumulated saving in 10 years of $50 per person (U.S. Public Health Service).

More impressive than per capita saving from the reduced pollution ($34) is the accrued value of the fossil fuels that we would not use and that would appreciate over the 10-year period. Thus, we can see that conservation and efficiency are not just a matter of superior resource management but have significant side benefits. Extending these benefits into the long term and beyond involves multibillion dollar savings that could well be applied to redressing income, health and education maldistributions. The savings contribute to the feasibility by 1995, of a guaranteed annual income for that part of our population in the very lowest income bracket. We have indicated that we are not necessarily sacrificing our economic goals through the conservation measures we have recommended. Nevertheless, we must conclude that for the success of our proposal we must overcome serious obstacles that are more in the social than technical area. We believe, however, that through a program of public involvement, information and education we can remove the barriers to successful implementation of energy conservation.

Society

Many of the social impacts of energy conservation policies have already been discussed in the sections above. Most environmental impacts are accompanied by social impacts; this is particularly true for production in frontier areas. Thus, reduced energy production eliminates some of

6. Energy, Mines & Resources, *An Energy Policy for Canada*, Information Canada, Ottawa, 1973.
7. Peter Maniate and Donald C. Carter, *Pollution Control Costs for Canada*, Policy Branch, Environment Canada, November 1973.

these adverse effects, particularly those related to social damage to native peoples who are already opposed legally and morally to the disruption of their habitats. As pointed out in the environmental section, saved capital would allow Canada to redirect some or all of its investment funds to socially useful projects such as improved equity, housing and health and an enhanced quality of life.

Added to these national benefits are those related to the reducing of international tensions through a conservation program which lowers our rates of consumption of critical materials. This at least provides a possibility for a more equitable global distribution of world resources.

Policy Making

This is possibly the most important area where an energy conservation program can have beneficial impacts. Technological strategies are time sensitive. The range and flexibility of energy technology options is enhanced by an improved supply situation for a particular demand goal. Through the energy savings achieved by conservation and efficiency we increase the future time in which we must develop the necessary substitutions and transfers.

To conclude, we have attempted to make a case for conservation in terms of both national and international goals and needs. We have seized on the historical situation of disruption of supply from the Mid-East to support our view that we require energy conservation policies. But this is not our major argument. Basically we are proposing a single form of conservation policy at this time – demand reduction through efficiency measures which do not decrease the effective consumption and therefore do not decrease the level of economic activity. If we return to our efficiency equation we can reformulate it as:

INPUT = OUTPUT + WASTE.

By decreasing the waste factor through higher efficiency we can achieve any particular output goal at a lower input. We will refer to this as a "technical fix" scenario using the terminology of the Ford Foundation Study (Appendix D, no. 9).

II. Methodology of Efficiency and Conservation Measures

First, it should be noted that it was not possible with the limited time and resources to do much original investigation into the potential savings accruing from implementing either social or technical measures. The information has been derived from existing studies mainly in the U.S. and partly in Canada and, in addition, from the actual experience of the U.S. during the period of the Mid-East oil embargo. Several well-documented, costly, overall research studies on conservation and efficiency conducted in the U.S. were the main source of information. However, spot checks were made by comparing a particular value for an energy saving with many independent studies in that particular area. This was done especially in the case of transportation, as well as for residential and commercial space heating and cooling where several in-depth studies of these sectors alone have been published. In fact, it was only these two latter sectors where it was possible to detail and quantify the savings.

The Ford Foundation study, "Exploring Energy Choices", was not available at the time of writing this study and only a preliminary version was at hand (Appendix D, no. 9). However, the use of the "scenario" method for posing various policy options is attractive and avoids some of the conceptual problems in the use of the term "standard forecast" (as in *An Energy Policy for Canada,* Energy Mines and Resources). The forecast used in the scenario method is really a form of judgemental demand prediction whereas the more precise term "projection" is an extension of past trends into the future. It is therefore a better form of identification to refer to an "historical growth" scenario as that projection which extends the past trend in energy demand growth into the future. It is true there are certain gross assumptions behind EMR's low, high and "standard forecasts". However, if one were to enumerate the assumptions in detail one could extend the range of these differences considerably. In order to avoid such complexity we will continue to use the "standard forecast" growth curve, but will refer to it as the "historic growth" scenario. We shall also assume it represents projected growth without anticipated savings.

The "historical growth" scenario is the energy growth pattern of the past 25 years. For Canada, primary energy consumption grew at a compounded annual rate of 4.4 per cent between 1950 and 1970. The projection involving various energy conservation and efficiency measures is called the "technical fix" scenario and corresponds to the growth pattern developed in this study. The Ford Foundation preliminary report poses a third general option, the "zero energy growth" scenario which we have not considered because it is beyond the scope of this study. Each of these major scenarios or policy choices then imposes its own sets of varying energy supply options and technological strategies for fulfillment. More than one mix of supply options can achieve the particular goals of each of these scenarios. The merits and disadvantages of each of these can then be described and analyzed. The "technical fix" scenario, for example, involves an exponential growth rate of one-half that of "historical growth" and can achieve this through high or low nuclear expansion combined with different mixes of other energy technologies and materials. Both the Ford and the Rand study (Appendix D, no. 7) claim that the "technical fix" scenario can achieve large energy savings without seriously affecting net demand and therefore with virtually no effect on the level of industrial activity and without any serious social dislocation. In addition, the "technical fix" scenario leads to some social and environmental benefits. In summary, the scenarios clarify options. Options determine a variety of strategies and these different strategies can be assessed by criteria of social, economic and environmental effectiveness.

Aspects of methodology were also derived from existing studies. In particular, the examination of energy use by sector, the selection of high pay-off conservation and efficiency measures within a sector, and the application of the accrued savings over three time periods, short, medium and long term, were all adopted. These time periods had to be modified since they were derived from studies already part of the past that assumed that the selected measures had been already implemented one or two years ago. As a reasonable compromise, durations of time periods have been assumed as follows:

Short term	1975 – 1980
Mid term	1980 – 1985
Long term	1985 – 1995

In our choice of time horizons we decided to mediate between conventional economic forecasting methods and those procedures used in comparable energy conservation studies. The traditional economic time horizons for decision or implementation of policy are the short run, the long run and the very long run. The total time horizon is simply a matter of convenience accommodating our span of interest. The content of these terms is understood as follows. The short run is the time period in which the assumed measures are based on an existing and largely stable stock of physical and social resources, i.e., on existing technologies, techniques, social behaviour and attitudes. The framework of the long run is the realization of known technical possibilities all of which are at some stage of development in the broad technical spectrum from the R & D stage to commercial application. The very long run is the time horizon for extending the known bounds of existing technical possibilities to highly innovative developments, existing perhaps only in the realm of imaginative and creative thought and rational possibility. These bounds are then translated into time "runs", periods or terms from the present to some period in the future comprising the very long run. It should be emphasized that this method focusses on both the physical-technical and social-behavioural limits of the particular time periods. In a simple sense we postulate a set of time scales moving from an existing, fixed inventory or stock of physical and social factors to innovations in both areas. We may then postulate that, on the basis of decisions made at the beginning of the period, it is possible to eliminate energy wastes by the end of each time run through particular measures.

As suggested we have chosen to opt for a compromise between the economic methodology for time horizons and that established in similar studies of energy conservation and efficiency. Thus our time periods, identified as the short, mid and long term, are consistent with the first two of the time horizons used in economics and we have eliminated the very long run. The total time period to be studied is the next 20 years, i.e., to the year 1995. All the time terms will deal with what have already been conceived as the technical and social modifications and developments necessary to achieve a meaningful reduction in energy wastes through conservation and efficiency measures applied in a rational and orderly manner.

In general the short term represents those measures which relate to the improvement of policy, regulation, procedure, management, etc. without any fundamental changes in the existing technical and social inventory. The short term measures can thus be applied immediately or after a short initial period for implementation. Such a program of short-term measures will not be homogeneous in effectiveness and the savings should be viewed as a distribution over time. Each short-term measure will have a different history of effective implementation. During such a program to eliminate waste certain physical and social changes will be achieved more or less quickly and more or less fully. We cannot however quantify the precise distribution over time and will use average values to represent aggregate effects.

The mid-term measures for combating waste are those which require more lead time than the short term. In general, they are composed of some minor changes in the physical and social inventory as well as some further intensification of measures developed in the short term. Finally, the long term represents the time required for measures both physical and social, which, while based on a stock of known techniques and approaches, require a long time period for development and implementation.

In a real situation one cannot separate time into such distinct functional arrangements. Attitudes that may be dominant in the future are already present. Physical plant changes and technological changes that are available now but not yet in existence can be applied to some new and replacement plants even in the short term and more so in subsequent terms depending on the level of development. But in general certain changes are confined by the constraints of time as described earlier.

In our methodology we shall assume that the per cent savings realized in each term are incremental throughout subsequent terms and thus may be added to the new per cent savings in each subsequent term as long as we are not using an identical measure applied to a different per cent of a population. That is, the per cent savings in the short term may be continued into the medium and long terms and may be added to the new savings from measures unique to each of these terms. This assumption can be criticized on many grounds but nevertheless has been used in all other major studies on conservation and efficiency. As an example, one obvious fallacy is that a particular enhancement of efficiency in the short term, operating on the population of physical plant or product existing in that period, will undoubtedly be less effective on a future population whose average efficiency has been enhanced by a number of major changes. This is merely an expression of the law of diminishing returns or of the compounding effect. Superior means of combating waste will ultimately eliminate earlier, less efficient means. However, these more efficient means could well increase the average effectiveness. Thus, one may argue that the group of measures which are supported by attitudinal and behavioural changes will be more effective in time and thus result in larger per cent savings in the future. Some measures proposed in this study are a mix of voluntary and involuntary changes. How the effectiveness of this group of measures changes in time is difficult to assess. With other measures, we may assume that there will be no radical change in the physical inventory even into our long term and therefore procedural measures supported by attitude change can be increasingly effective. Many of the measures we are proposing are continuous in time rather than requiring specific lead times. We are dealing entirely with existing proven technologies, techniques, procedures and supportive attitudes.

In general we can distinguish between those measures that are directly sensitive to human responsiveness in use of energy and those that rest on totally new designs and planned systems. A simple example are speed limits, sound maintenance, etc., compared with automobiles of a new design, of higher intrinsic efficiency, or even of limited speed. Dealing with the former it is conceivable that, in time, an increasing percentage of populations will tend to adopt or support efficiency measures. In the latter category (essentially involuntary) new systems of a higher order of efficiency will tend to eliminate those measures requiring supportive responses.

For all the above reasons it would be extremely difficult, and beyond the scope of this study, to judge the changing effectiveness of each particular measure in time. Thus we are assuming, with support of other studies, that on the average all the measures of each term expressed as a per cent saving can be added to the per cent saving in each subsequent term. As we have argued, our assupmtion is that gains and losses in effectiveness will tend to balance out. Since our resulting savings are considerably lower than those derived in other major studies, the above assumption can hardly be faulted.

As suggested for each of these periods, certain kinds of measures are appropriate in that they are largely known and available for the short and mid term but require some research and development or lead and implementation time for the long term.. All measures are clearly identified for each of the time periods keeping in mind that while all seem to be theoretically sound they are not equal in terms of effectiveness of implementation. This may be for a variety of reasons ranging from economic to cultural barriers, however this study will not detail either the barriers or the individual cost-effectiveness of each measure.

Two problems arise from basing our quantitative analysis on U.S. sources. The first is concerned with the differences in sectoral energy consumption between the U.S. and Canada. This means that the total energy savings will be different even though the per cent savings per sector are generally assumed to be comparable. Thus it is necessary to recalculate all the savings for the specific energy production and consumption patterns in Canada. Secondly, within a particular sector such as transportation or residential/commercial the detailed distribution of energy consumption is not identical to that in the U.S. Therefore, in applying the various savings on a detailed level, recalculation is required to conform to the Canadian pattern.

In general, despite the care exercised, the estimates are based on assumptions that, to a varying degree, are arbitrary, and on information that is limited. Thus, the reliability of actual derived numbers may be questioned but not the major thrust of the argument. More explicit and rigorous assumptions, together with a richer data base would enable more accurate and documented estimates. It is not the precision of the figures but the order of magnitude of opportunities indicated that are significant. Basically, substantial savings in future energy consumption can be made without seriously affecting Canadian social and economic goals. It should further be noted that not all the measures suggested have been quantified, both because of lack of definite criteria for conservation effectiveness (p. 31) and because of the almost total absence of creditable data.

Usually, we have approached conservation via enhanced efficiency and only to a lesser degree through demand management. We have not considered pure conservation strategies with high pay-off savings such as increased durability of goods and major recycling schemes.

No serious attempt has been made in any other studies to trace out the rate and path of implementation consistent with the particular measures applied. In almost all cases it is simply assumed that certain savings will accumulate linearly and be suddenly and totally applied to the year ending the time period under consideration. In fact some measures are immediately applicable while others involve varying time lags. Thus a mandatory 55 mph limit produces immediate savings. Other studies assume that the annual savings recorded at the year ending the time period will have been achieved by that time. In most cases a range of savings from low to high are calculated. In the studies consulted when the savings are applied to the year ending the time period, a new idealized exponential curve representing consumption is extrapolated to the end of the second or mid period. Again the savings for the mid period are treated similarly, giving a new consumption – and so on through the long term to the year 2000.

In our methodology we shall differ in one minor and one major respect from that discussed above. The minor difference is that we shall use averages (arithmetical means) of the low and high savings derived from other studies. Wherever possible we shall consider values for savings that have been replicated in independent studies as being most reliable. Where such replications do not exist we shall attempt to derive values for savings ourselves. Then we shall apply the total savings at the end of the long term to the "standard" projection of energy consumption (EMR, *An Energy Policy for Canada, Phase I,* 1973, p. 24, chart 2) and plot a new idealized exponential growth curve for the entire time horizon.

The major innovation of this study is an attempt to trace out the rate and path of implementation of conservation measures in a plausible and realistic manner over each of the time periods involved. This rate and path of implementation will rest on a number of assumptions to be spelled out for each subsector area under consideration. In general, they will be based on two assumptions. The first is that implemented changes in the short and mid term will apply separately and differentially to new and old populations of industrial, residential/commercial or energy conversion plants (electrical utilities). Secondly, changes will not apply to all of the populations but only to certain reasonable proportions. Therefore, the rate of implementation will be affected by the rate of growth of these populations of products and processes. In some cases and for all terms we can consider some of the implemented changes to apply to old populations. For example, thermal insulation can be applied to existing homes and radial tires to autos. We have developed a mathematical model for the mode of implementation and will use this to plot the path and rate of savings. In all cases, the assumptions, the method used and the individual savings for that particular case will be elaborated carefully. This latter aspect of this methodology adds an element of credibility to the conservation and efficiency measures recommended and avoids the over-simplified assumptions concerning the rate and path of implementation. It is here that detailed data specific to the Canadian scene are required. However, since the estimated savings by our method tend to fall at or below the range described in several other studies, the additional value of a method including consideration of the mode of implementation is questionable.

The energy sectors usually described in energy statistics are also appropriate for our analysis of savings. These are:

1. Transportation
2. Residential and Commercial
3. Electrical Utilities
4. General Industry

It should be noted that the savings in Electrical Utilities exclude thermal generation plants because the savings from this conversion process are absorbed in other sectors, mainly Residential/Commercial and General Industry. These latter savings lie mainly in improved efficiencies by utilization of waste heat. The other savings designated as Electrical Utilities above are derived mainly from smoothing out requirements for capacity, altering rate structure and decreasing demand, i.e., they are concerned with the actual supply of electricity.

In summary, while a few pure conservation measures will be discussed, i.e., the actual reduction of consumption, the major theme will be the achievement of savings through enhanced efficiencies of existing modes of production and consumption. To a lesser degree some demand management measures will be considered. Several other kinds of conservation measures seem to have relative significance and will be discussed separately toward the end of this study.

Path of Implementation of Savings

This aspect of the methodology is an attempt to associate the path of implementation of the various savings discussed on pp. 31–34 with the expected growth rate in each of the four sectors concerned. The major conservation saving will apply to new populations but, where feasible, certain measures may qualify for old populations. For example, it may be seen by examining the kinds of saving measures in the residential/commercial sector that both old and new populations may be considered for all periods or terms. On the other hand, in the case of transportation, the measures for the long term involving technological developments are not yet commercially available and therefore cannot be applied to the preceding terms.

Each individual case has been considered on its merits and represents a consensus of views assembled and analyzed from a number of independent studies. These studies provide the basis for choosing the proportion of population, new and old, affected by the measures and the average rate of savings as a percentage. By multiplying this rate of savings by the per cent population affected, we obtain the per cent sectoral savings in energy. An advantage of this method is that it associates the rate of implementation, the enhanced efficiency through specific measures and the net effective sectoral savings achieved in the year ending each of the three periods. A summary of this analysis is shown in Appendix C, Table 1. Tables 2, 3 and 4 provide the sectoral demand and growth indices and are derived mainly from *An Energy Policy for Canada.*

To sum up, the method described in this section accomplishes what all other studies of conservation and efficiency have neglected. This is to develop a reasonable strategy for an aggregation method, as well as for a rate and path of implementation of specific conservation measures. The fact that there is a reasonable correlation between this analysis and the results of other studies enhances the value of the method used. For example, the independent estimate by C.H. West of Ontario Hydro (Appendix D, no. 8) concludes that existing conservation methods could reduce energy consumption by 25 per cent in the year 2000. Finally, it should be noted that the detailed analysis for all the sectors and for each time period are shown in Appendix D. Table 5 provides the new "conservative" consumption per sector and term. The saving, for example, achieved by 1995 amounts to 2.40 x 10^{15} Btu and reduces the "standard" projection from 16.2 to 13.8 x 10^{15} Btu.

The path of implementation rate assumes the rate of savings to be proportional to the time interval. The interesting conclusion is that fitting a valid exponential curve between two consumption levels, which is the essence of this second method, corresponds closely to "linear implementation". The arithmetic of developing each of the overall savings for each term and each sector is as follows. First, we derive an average increase in efficiency using independent studies (Appendix D) for each particular measure within a sector. This is then weighted in proportion to the population affected. In some cases the change applies to an entire sector, sub-sector or activity, for example, increased thermal efficiency for the residential sector is separately derived for heating and cooling. In other cases the situation is more complicated. As an illustration, if we are dealing with measures that increase automobile efficiency, the enhanced efficiency applies only to the proportion of energy consumed by the auto within the transportation sector. We would then multiply the fraction of the automobile population affected by the fractional increase in efficiency and by the fraction which the automobile energy represents in terms of the total transportation consumption. If for instance the use of radial tires on autos will increase fuel efficiency by 7.5 per cent on the average and autos make up 75 per cent of the transportation sector and 50 per cent of the auto population adopt this measure, then the fractional savings of the sector are 0.075 x 0.75 x 0.50 = 0.028 or 2.8 per cent. We then add all these various fractional savings to derive a total sector saving for each period. These appear in the summary of savings, Table 1.

Perhaps, we should now clarify the use of the term "population". Population does not always refer to the number of units or installations, i.e., the number of automobiles, electrical utilities or residences, but to the energy consumed by each of the four sectors. The terms new and old populations therefore refer to the growth in energy consumption of a particular sector over a particular period and to the existing level of energy consumption in that sector at the beginning of the period. To make this explicit, if we examine Table 4 we may note that in the base year, 1975, the "old population" in each sector is represented by 100 per cent.

The reason for this approach has been partly described earlier in the section on methodology, i.e., to associate the implementation with the growth characteristics of the sector. It is necessary to use energy consumption in lieu of unit populations because each sector is too complex in its mix of sub-units. In the residential sector, for example, we have single family, multi-family, high-rise and other types of dwellings. In the transportation sector we have autos, buses, transport vehicles, railroads, aeroplanes, etc. Some measures apply only to the automobile while other measures apply to specific modes of transport, i.e., transfers of freight from one mode to another of higher efficiency (affecting aeroplanes, trucks and railroads).

When, for example, at the end of the short term period, 50 per cent of the new and 10 per cent of the old populations are affected by the saving measures, we mean that 50 per cent of the energy growth in that sector by 1980 and 10 per cent of the energy consumed in 1975 is affected. With autos, for example, the new population means the total number of new cars built between 1975 and 1980, while the old population represents cars in existence in 1975, i.e., 100 per cent. The sectoral savings, in addition, have been calculated independently on the basis of specific measures applied to specific proportions and aspects of a sector or sub-sector. By totalling these individual savings we get the total savings for that sector.

Certain measures can only apply to new populations in a literal sense as new units. For example, a reduction in average automobile fuel consumption can occur through more efficient engines in new automobiles. On the other hand, the use of radial tires can apply to a proportion of all autos, either of new or old vintage. The transfer of freight from one mode to another can apply to a proportion of the entire actual populations of the two modes, new and old. Each of the measures of given increased efficiency must therefore be applied to a specific sub-sector and to a definite population proportion of that sub-sector. This will give a specific energy saving which can be expressed as a per cent of the sector's energy consumption and is applied to the year ending each of the terms.

To illustrate our method we have described the procedure for three sectors, transportation, residential and industrial in Appendix B, although the latter sector is treated grossly in terms of consensus efficiencies.

It should be noted that the case of transportation is exceptional. This is so because of the complexity of the sub-sector components, i.e., the various modes and functions of transport. Also over time, the mix and modes are growing differently. Techniques for increased efficiency in one particular mode do not necessarily apply to another. Moreover, certain saving measures involve transference, for example, from private to public passenger transport or from a low efficiency freight moving mode to a higher efficiency one. Still other measures such as those intended to reduce or restrict the use of the private auto in urban cities or intercity transport have their own complexities. The net result is that the transportation sector must be treated by a modified methodology. Instead of dealing with fixed proportions of old and new populations as in the other sectors, each specific measure must be applied to a specific population of a particular mode or several modes. Then the separate individual savings from each measure are totalled to obtain the sector saving. While, in part, we do this in the Residential and Commercial sector, we nevertheless deal with constant proportions of old and new populations. It should be noted that in the mid and long terms we deal with a totally different group of old populations. What is significant is that in our detailed method, all cases correspond closely to a consensus of savings obtained from a variety of independent studies. For example, at least four studies anticipate 20 per cent savings by 1985 in the transportation sector. Only one of these studies is detailed, but it does not take into account implementation by term or time units.

In conclusion, the summary of savings, Appendix C, Table 1, follows the general methodology described earlier, except for the transportation sector in which there are fixed proportions of population involved for each sub-sector and term that cannot be uniform for the entire sector. Also, despite our explanation that the term "population" is not necessarily synonymous with the number of individual units, but relates to energy consumption, a correspondence does, in many cases, exist. For example, with respect to population in the case of autos and trucks, the number of units and the energy consumed are certainly related. But in all cases the significance of this method is that implementation rates are associated with sectoral growth. A complicating factor is the literal replacement of old populations by new, i.e., old cars junked or old buildings demolished and replaced. To compensate for this situation we have increased the proportion of new populations affected as we proceed from short- to long-term conservation measures.

Implementation Techniques and Criteria for Conservation Effectiveness

It may be noted that the various conservation measures recommended in this study straddle a broad range of implementation techniques. In the debate about the efficacy of voluntary versus mandatory measures, or positive versus negative incentives, or imposed price control against "natural" market allocations and controls, it should be recognized that all have a suitable area of application. The relative effectiveness varies from case to case and often cannot be anticipated. No technique is put forward as exclusive, or even to be advanced preferentially, but as tentative and subject to modification or replacement. In particular, it should be recognized that each technique has certain advantages and disadvantages. Voluntary restraint is limited by understanding and commitment. Both of these limitations of mandatory restrictions may be exemplified in the lowered speed limits and gasless Sundays in the U.S. Gas rationing does not necessarily distinguish between vital and marginal needs of users, while higher prices tend to punish lower and fixed income groups. Some economists have argued that energy price increases will not be regressive on balance since total energy use tends to be income-elastic. In general, if this study favours any particular technique, it does so in the spirit of openness. One will have to test the effectiveness in a real situation, however, some of the experience of the U.S. can be of assistance. One point cannot be overemphasized. Without a broad involvement of the public, supported by educational and informational programs, many conservation policies will encounter obstacles to fulfillment. Such consultation should especially extend to all groups likely to be selectively affected by a particular measure.

Our techniques of implementation fall into three general areas which may be described as (1) Voluntary, (2) Price or Market Mechanisms, and (3) Proscriptive or Regulatory, i.e., mandatory, involving time use restrictions, consumption quantity restrictions, establishment of legal standards, etc. The important aspect is to match each particular measure with the appropriate implementation techniques. Sometimes multiple techniques may be necessary. It is possible to enunciate some general principles concerning conservation measures and the incurring of social costs. If any conservation measure involving higher efficiencies or reduced consumption of energy leads to a re-direction in the quantity of goods and services produced or causes a shift in the nature of those goods and services, it will entail some social costs. Thus the most appropriate energy efficiency measures would have the following characteristics.

1. Energy savings would not necessarily involve a reduction in the quantity of goods and services available, i.e., they would have high economic effectiveness.

2. The measures applied would not involve a serious shift in the kinds or mix of goods and services produced.

3. The cost of implementation of efficiency measures should be lower than the value of the savings, i.e., a positive cost-effectiveness.

4. The energy of implementation should be significantly lower than the energy saved, i.e., net total energy efficiency increase.

5. The measures should be matched by the most appropriate techniques of implementation, as assessed by testing.

6. Social mechanisms should be planned to minimize costs and to avoid social costs being borne only by small affected groups where it is not possible to avoid distributional shifts in labour and capital.

Various studies of the energy supply-demand complex deal with the question of the effectiveness of price on demand reduction and in stimulating supply responsiveness by industry. The most comprehensive of these are the MIT study[1], the Rand study (Appendix D, no. 7), the SRI study [2], and the Ford Foundation study (Appendix D, no. 9). An important fact is that these studies do not show agreement concerning the power of market mechanisms to reduce demand. The SRI study clearly suggests that the use of electricity, for example, is not very responsive to price. At best there is a consensus that price alone cannot achieve the reduced demand required by supply conditions. This is not to deny that some of these studies still consider pricing to be the major factor in controlling certain energy demands. It is interesting that the

1. Policy Study Group of the M.I.T. Energy Laboratory, *Energy Self-Sufficiency: An Economic Evaluation,* 1974.

2. Stanford Research Institute Study for the Utility Industries of California, 1973, as cited in M. Fitzgerald, "Has State Government Done Its Part?", *California Journal,* June 1973.

MIT study concludes that demand reduction by "conservation" (mainly via efficiency) would be 16 per cent by 1980.

Actually almost all studies agree on the effectiveness and quantity of demand reduction achieved through various efficiency measures. It is for these reasons that we are not recommending in this study that pricing techniques and policies are exclusive measures for controlling demand. At the same time we are not denying that prices are a major factor in a policy of reducing demand. We consider, however, that there is considerable social inequity involved in achieving reduced demand by high prices, as well as serious economic backlashes. During the recent energy crisis, the tourist industries of states like California and Vermont suffered serious revenue cutbacks largely attributed to the high price of gasoline. And the price remains high despite a subsequent inventory glut of crude oil. Oil companies are now running short of tanks to store more. Again the assumption that large supplies would reduce prices has not been borne out in the short run. However, OPEC controls its level of aggregated production to support prices internationally. Thus we are neither assuming that pricing techniques are the exclusive means to reduce demand nor are we certain that economic disbenefits may automatically prohibit energy conservation.

Measures that are immediately available for high payoff in terms of savings are those which do not involve significant lead times for implementation. A case in point of such an energy management measure is the voluntary setting of thermostats a few degrees lower in winter and, where air conditioning is widely used, a few degrees higher in summer. It can also be aided, of course, by price-oriented techniques or a combination of both. Reduced lighting, including elimination of decorative lighting in the commercial sector, is a significant measure keeping in mind that in cold periods lighting decreases the heat load and in warm periods it increases the air conditioning load. This latter measure plus active thermal management in the general industry sector correspond closely to our criteria for sound conservation and have high savings payoffs. All these savings are immediately effective since they do not involve lags in implementation. One high payoff efficiency measure which certainly involves a cost, but one that can be traded off against energy costs to the householder, is the improvement of thermal insulation in the residential sector. Speed limits and gasless days are based on mandatory implementation techniques and result in significant energy savings. Car pooling, conceivably, could also be significant. This is a measure largely implemented by voluntary means. These measures also conform to our criteria of conservation effectiveness with the notable exception that lower consumption of gasoline without price adjustments specifically affects the service station operators. Moreover, without educational programs, lowered speed limits in the U.S. are not as successful as anticipated because of a lack of capacity to enforce the law. A real possibility in controlling speed is not through the driver but through design standards for the vehicle. Various measures recommended in this study might involve serious social costs and would require detailed cost-benefit analyses, feasibility studies and implementation policies designed to minimize costs and their unfair distribution. Because of this we have not quantified all measures described, limiting our estimates to those measures which conform to our criteria of effectiveness.

Detailed Analysis of Savings by Sector and Term

A. Transportation

Tables 2, 7, 9 and 10 in Appendix C show the amount of energy consumed by the transportation sector over the period 1975 to 1995, the efficiencies of various passenger and freight modes and the projected mix of transport modes. Translated into percentages, two striking trends emerge. The first is the significant increase in the air travel mode and the second the increase in the fuel consumption of the road travel mode, i.e., petroleum product consumers using all forms of internal combustion engines. Contrary to the common view that average horsepower of this sub-sector was decreasing a decade ago, a study[3] indicated that the aggregate horsepower and fuel consumption of internal combustion motor vehicles was still increasing. This in part reflects the increased use of mobile homes, campers, trailers, agricultural equipment, etc., as well as the increased unit size of truck transport. Despite a trend toward somewhat lower horsepower for the private passenger auto, two additional factors act against any mediating effect on fuel consumption. These are the extra power burden of auto emission control devices (despite Canada's stand on these by virtue of our trade relations we shall be obliged to follow the U.S. lead) and the steady increase in the automobile to population ratio (0.36 in 1975, 0.41 in 1980, 0.46 in 1985, and 0.47 in 1995). Fortunately, a counteracting trend is the use of catalytic mufflers (in some 1975 models), where an increased efficiency of 14 per cent over 1974 models is estimated. The transportation sector follows the commercial sector in having the greatest increase in fuel consumption, to 1995. Almost 60 per cent of all the petroleum used in Canada is absorbed by transportation and ancillary sectors. This dependence is projected to last right through our long-term period, beyond 1995.

The energy effectiveness in the transportation sector is measured on the basis of passenger-miles (PM) and ton-miles (TM), since the energy consumed is directly related to the inertial and frictional forces acting on the vehicle. Sheer weight, of course, is the biggest single cause of fuel consumption. The values of energy per PM and TM also give us a measure of efficiency of various modes of travel in the transportation

3. Ralph C. Lenz Jr., "Forecasts of Exploiting Technologies for Trend Extrapolation", in *Technological Forecasting*, Prentice Hall, 1965.

sector. Table 7 indicates these relative efficiencies in terms of Btu per PM and Btu per TM.

An analysis of these tables provide a general basis for achieving an enhanced fuel economy. Four different measures may be derived: (1) increase vehicle efficiency, (2) increase occupancy, i.e., passengers or loads, (3) shift demand from low to higher energy efficiency modes, and (4) reduce overall demand. As in all of our analyses of conservation measures the general principles involved are: (1) to apply both technical and social means in attaining conservation, (2) to develop a reasonable implementation mode and time for each sector and sub-sector, (3) to concentrate on further techniques for short- and mid-term periods while recommending technological changes involving R & D for the long term, (4) to minimize discontinuities and dislocations in the Canadian economy, and (5) to use an average of various studies of potential energy savings through specific measures.

Short-Term Measures and Savings (Transportation Sector)

1. Change the mix of passenger car population to a higher proportion of small cars (26 mpg, Imp.) by education, persuasion, tax incentives, and driver education. Environmental Protection Agency (U.S.) (EPA) figures for 1973 show a range of 29.1 mpg. U.S. for the Honda Civic and 6.8 for the Toronado.)

2. Eliminate a portion of urban congestion by embargoed traffic zones, inner-city prohibition of private autos, increased fringe parking, increased urban parking costs, etc.

3. Achieve success in lowering maximum highway speeds by 10 mph through stricter penalties, education programs, etc. Driver education generally can be an extremely significant factor in energy conservation. It should be noted that efficiency drops off faster than the inverse of the speed.

4. Persuade commuters to increase use of car pools by tax or toll, and reduce peak hour road use by tax or toll.

5. Shift proportion of commuters (to and from city centres) to dedicated bus service and improved mass transit systems by decreasing mass transit fares through subsidy and matching grants, priority bus lane zones and priority for buses at intersections, car pooling to trunk lines, etc.

6. Shift proportion of inter-city auto and air passengers to inter-city bus and rail, evenly, by banning subsidy of short flights by long flights, improving rail service, instituting rapid surface systems for short haul inter-city, etc. This should be accomplished by a combination of subsidy, matching grants and regulations.

7. Shift a proportion of inter-city trucking to rail freight by improving rail service, lowering freight rates, encouraging piggybacking and in general consolidating and organizing freight movement. Again, this can be implemented through subsidies and tax incentives.

8. Shift a significant proportion of short haul air passengers to

inter-city bus and rail by methods discussed in No. 6.[4] (The STOL system would also represent an energy saving for short hauls.)

9. Decrease demand for transportation in general by increased incentives for walking or biking distances less than three miles, by improving walking and biking paths, providing walkers and bikers with sheltered rest and refreshment places; promote local facilities, i.e., community entertainment, dining, recreation, shopping, etc. This can be accomplished in part by subsidy but preferably by persuasion and educational programs.

The sectoral savings have been estimated at various figures from 26.29 per cent to 10 per cent. (Appendix D, no. 1 and 10).

Mid-Term Measures, 1980–1985 (Transportation)

1. Continue to apply all of the short-term measures and the means of implementing them.

2. Implement fuel economy by technology now available:

a) improvements in carburetion, injection, ignition and air-induction;
b) broad use of radial-ply tires;
c) modest re-design to reduce aero-drag at highest speeds;
d) an average weight reduction over the short-term car mix of 10 per cent. (EPA's 1973 figures indicate a performance reduction of one mpg for every 100 lb increase in weight of cars between 2000 and 3000 lbs);[5]
e) improved propulsion system for buses;
f) improve truck engines (possibly retrofitting fleets).

3. Increase fuel costs by taxes.

4. Enforce efficiency standards by regulation.

5. Apply selective registration tax on size, power and power attachments of autos plus regulations.

6. Control auto size/loading and entry into central business districts by regulation.

7. Improve balance between various travel modes by subsidy/matching grants:

a) improved feeder service (dial-a-bus);
b) increased bans on autos in city centre;
c) improved mass transit;
d) conversion of part of city centre to pedestrian-oriented clusters;
e) improved rail networks for freight and passenger;
f) continued aids to walking and biking.

The general consensus is a total sectoral saving of between 20 and

4. Experience in the U.S. in the winter of 1974 indicated that some air lines actually increased profits by reducing the number of flights due to improved passenger density per flight. Also not only energy efficiency is achieved by bus service between Montreal and Ottawa but the economies are superior compared to air travel while the time is approximately equal.

5. This would cause a saving of over 2 mpg for an average car of 4000 lbs. at present.

22 per cent with an increased efficiency for the population affected of about 33 per cent.

Long-Term, 1985–1995, (Transportation)

1. Continue all short- and mid-term measures to larger proportion of both new and old populations.

2. Install new fuel economy technology for cars, buses and trucks, for example, smaller engine with booster to meet peak demand or lean-mixture engine or engine used with an infinitely variable transmission (either of these will increase efficiency 30 per cent).[6] Install hybrid energy storing system allowing constant maximum loads (100 per cent improvement).

3. Institute R & D programs for advanced propulsion systems (could obtain increased efficiency of 100 per cent), advanced traffic control, new transportation systems, new freight handling/distribution systems, planned urban development and reconstruction to restrict demand (implemented by regulation and matching grants).

4. Convert, possibly on a broad scale to Wankel engines using a modulization of single rotors bolted together to save on energy of production.

Combination of all the short-, mid- and long-term measures lead to a sector energy saving of 29 per cent.

B. Residential-Commercial

Table 2 in Appendix C indicates the amount of energy consumed by the residential and commercial sectors over the period 1975 to 2000, the various projections being based on EMR's "standard" forecast. The very high growth rate for the commercial sector, estimated to increase by almost 4 times in the 25-year period is striking compared to the more modest increase in the residential sector of about 2 times. This high energy growth in the commercial sector reflects the growth of the service industry in our society plus the very high level of building activity. The residential and commercial sectors are usually grouped together as a single consuming sector because the most significant energy demands in both sectors are space heating and cooling followed by water heating, refrigeration and cooking. In both sectors these demands account for over 75 per cent of the total energy consumption with a higher percentage in the residential sector. *An Energy Policy for Canada* projects a significant increase in electrical use by the commercial sector, accounting in 1995 for over 50 per cent of the total electrical demand. This demand for electricity is closely followed by the industrial sector. Table 3 is particularly informative since it describes the projected mix of hydro and thermal generation showing the significant increase in waste heat as the proportion of hydro decreases relative to thermal.

6. J. K. Dubowitz, and W. Z. Fraize, *Transportation Energy and Environmental Issues*, The Mitre Corporation, McLean, Virginia, February 1972, p. 18.

It is from the above analysis of the commercial sector's demand and from the particular nature of the energy requirements coupled to the increased availability of waste heat that we can derive high payoff energy savings. The intrinsic wastefulness of thermal electrical use is closely related to the conservation and efficiency measures proposed to attain these savings. When it is understood that heating with electricity from thermal plants is 67 per cent as efficient (Appendix D, no 2), as heating by an in-house well-designed oil or gas furnace, one can understand the potential for saving. This argument, of course, would not apply to hydro-electricity or nuclear generation. There is very little disagreement among the various studies of energy savings in the residential and commercial sector. The increased efficiencies reported in Appendix D, no. 1, 3, 4, 19 and 23 are in very close agreement.

Large public buildings are voracious consumers of energy. The commercial sector includes all commercial buildings, government institutions, all service and recreational facilities, the wholesale and retail trade, as well as commercial farms, fisheries, etc. The impact of design on potential savings in the commercial sector cannot be exaggerated. Many independent experts in the field of engineering and architectural design of large commercial or residential buildings agree on the potentiality of savings. The possibility of district heating particularly by waste heat from thermal generators or incinerators is an example. This question of the role of design on energy savings will be treated separately in this study since it is potentially one of the major devices in the conservation of energy in all sectors.

Nevertheless certain aspects of design as related to the Residential-Commercial sector are worth examining. Both Richard G. Stein of Richard G. Stein and Associates, Architects, of New York City (App. D, no. 20) and Fred S. Dubin of Dubin-Mindell-Bloome Associates, Consulting Engineers, New York City (idem), designers of large commercial buildings, claim it is possible to save 20 to 25 per cent of the energy required to construct and maintain buildings. When one considers that between 5 and 10 per cent of Canada's total electrical consumption is used in building construction, directly and indirectly, and that the commercial sector is expected to consume 50 per cent of our total electrical output after 1985 (it uses 25 per cent now), one sees the significance of these savings. They are achieved largely through improved design, selection of materials of construction, the adoption of proper building codes and regulations, the use of the correct and adequate level and positioning of illumination and, wherever possible, the use of central heating and cooling, preferably not electrical, and for the former, preferably waste heat, i.e., from thermal generators. By using absorption type (non-electrical) central cooling systems still further energy savings can be accomplished. A combination of these techniques is sometimes referred to as a total energy system and involves the use of heat pumps.

Several cases can be cited, prototypical and actual. In a prototypical 50-storey building (about 1 million square feet) using the most widely accepted design standards the energy consumption was estimated at 36.8 million kwh per year (about one-half of that of the World Trade Center in New York City). By applying new energy saving design techniques to this prototypical building its energy consumption dropped 52 per cent, i.e., from 4.24 x 10^{11} Btu per year to 2.09 x 10^{11} Btu. A significant proportion of this drop is achieved by using steam heat from generators or incinerators, that is by a reduction in the electrical heating load. Among actual examples, the use of Integrated Environmental Design in the U.K. to achieve heat-balanced buildings built with this design achieved energy savings of 50 per cent.

An even more interesting example involving the "total energy system" concept is Rochdale Village, New York. In this 170-acre housing complex 20 per cent savings over a conventional system have been achieved.[7]

With respect to conservation, while the use of known technologies can lead to significant savings, one cannot diminish the role of social techniques such as incentives through credits or penalties, standards, regulations, and public educational and information programs. Sweden has proved the success of the latter method (App. D, no. 1). If all the residential thermostats in Canada were set 2 degrees higher in summer and 2 degrees lower in winter, in 10 years we would achieve an accumulated saving of *1 per cent of our total fuel consumption in 1985* (or 0.08 x 10^{15} Btu, i.e., 17 per cent of this sector's total projected energy consumption). Of course, this kind of measure produces immediate results regardless of the fraction of the population involved.

The use of waste heat from thermal and nuclear power generation (growing at 10 per cent per year) is a large high-payoff fuel conservation area. The use of this heat for district heating schemes (App. D, no. 16, 18 and 19), intensive food production complexes (no. 16, and 19) and warm water irrigation has been widely reported and has been successfully implemented in various parts of the world. The problem still remains one of economic viability. A national policy will have to decide if conservation is critical and determining. Fifty per cent of the waste heat from the Pickering Nuclear Station near Toronto could supply the space heating needs of 680 000 homes (no. 19). The net energy conversion efficiency of thermal generators (including transmission losses) is only about 28 per cent; since we are going to be more dependent on this type of generation in the future we must solve the problems of using this low grade discard heat (25–40° C). There is the paradox that raising exhaust temperatures thereby making the waste heat more useful and plentiful, reduces the overall thermodynamic efficiency of the generating plant. This might be overcome by integrated urban, industrial and agricultural designs that maximize the total efficiency of large complex systems.

7. R.M.E. Diamant, "What is Total Energy", in *Total Energy*, Pergamon Press, Oxford, 1966.

As a matter of fact, electrical efficiency drops from 36 to 23 per cent in a modern thermal plant that rejects steam at 120° C rather than 30° C, but, if the increased rejected heat is used, the overall efficiency rises to about 80 per cent (App. D, no. 18 and 23). Of course, costs rise as well and the optimum must be sought. Many industrial activities such as chemical plants require large quantities of process steam (for example, the total energy facility at Sarnia), (App. D, no. 18) and certain other processing industries associated with agriculture and aquaculture will also be able to use waste heat. Moreover, waste heat can be used to develop refrigeration or chilling systems such as the ammonia or lithium-bromide absorption system. By using larger gas turbines and exhaust temperatures up to 140° C, the combination of electrical generation and waste heat utilization can raise total efficiencies significantly (App. D, no. 18). "Nuplex" (Nuclear Power Industrial Complex) systems indicate significant possibilities of energy savings (no. 16), including industrial water re-use concepts. The Nuplex concept can be applied equally well to total energy systems in the urban, residential and recreational use of waste heat. District heating and cooling, and sewage and water treatment have successfully applied waste heat. Temperatures required for some of the advanced systems are of the order of 60-80° C (no. 5). In many cases "slave" boilers are required for standby or demand stability purposes. At least one study suggests that for a hypothetical city the size of Greater Ottawa (about 400 000) the use of a city energy centre would allow a maximum savings of about 30 per cent in total energy consumption.[8]

Certain obvious techniques will be indicated in the detailed analysis of measures to save energy in the residential and commercial sector. But since space heating and cooling represent such a large proportion of the energy demand, improved insulation to the optimal level, i.e., the optimum balance between increased cost of insulation and savings in heating costs, is one of the major measures required. When one realizes that the difference in heat losses per inch of insulation from sub-optimal to optimal is on the average 3000 Btu/day/deg. F, one can understand the impact of improved insulation. In private discussions with the division of building research at the National Research Council we were informed that the 1975 residential standards for the Canadian Code for Residential Construction would include a provision to increase the insulation thickness to approximately 6 inches providing optimal insulation with heat savings of the order of 25 to 30 per cent over present residential structures. It would be far better if these standards were introduced into the National Building Code since CCRC applies only to CMHC housing. Coupling this with more efficient furnaces, air cooling and conditioning equipment would provide more substantial savings. Providing further

8. A.J. Millar *et al*, "Use of Steam-Electric Power Plants to Provide Thermal Energy to Urban Area", U.S.A. Oak Ridge National Laboratory (ORNL), Report ORNL-HUD-14, January 1971.

details for the proposed 1975 insulation regulations, NRC indicates that this will save the owner of a 1200 sq. ft. house $50.00 per year after a 5 to 8 year period for payment of the insulation. Moreover, between 30 and 40 per cent of all new housing starts after 1975 should follow the new standards (App. D, no. 23). Finally, on the subject of insulation, as well as heating and cooling equipment efficiencies, many of the measures can be applied to old as well as new populations.

Tables 1, 5 and 6 in Appendix C show the summary of savings for all sectors and the per cent of sectoral savings. The following are the detailed measures for each term.

Short-Term Measures and Savings (Residential and Commercial)

1. Reduce heat loss in winter and heat gain in summer in both new and old residential dwellings by using:

a) improved insulation
b) storm windows
c) caulking
d) door weather stripping.

2. Where possible improve heat gain and heat loss in commercial installations by appropriate measures. Both of these can be implemented by a combination of government loans and tax deductions for conservation, regulations and educational programs.

3. Adjust illumination levels to the recommended levels in the UK (about 25 per cent of the present levels in Canada and the USA) through proper design. This can be accomplished by the same methods as No. 1 and 2.[9]

4. Reduce infiltration of air in both residential and commercial sector by proper ventilation control and on-off systems.

5. Reduce hot water heating energy by improved efficiency of heat exchange equipment ("heat savers"); encourage use of waste heat on thermal generators, etc.

6. Encourage purchase of more efficient appliances. For example, air conditioners vary by a ratio of almost 3 to 1 in the energy required for the same amount of cooling. A disparity in efficiency of refrigerators, clothes dryers, washing machines and other appliances is also true. Also, frost-free refrigerators use much more energy than ones requiring defrosting. This could be implemented by a combination of regulations and education to the effect that all appliances are to be provided with energy consumption name-plates and this same information is to be used on price tags and in advertising. Also non-government consumer groups should be encouraged with government financial support to rate all appliances on energy consumption.

7. Develop improved combustion techniques for all heat exchange

9. An interesting example of an effective means for achieving this is cited in Appendix D, no. 9, whereby utilities finance insulating and other conservation costs for the homeowner through low interest loans repayable through utility bills. This life cycle costing usually takes one year for a break-even.

systems including furnaces. For example, using a blue flame oil burner or a natural gas furnace increases efficiencies to about 80 per cent (compared to the average oil furnace in the 1950s with efficiencies of 56 per cent.)

8. Encourage the use of a heat "saver", which is simply a heat recovery system from losses in residential home heating.

9. Integrate furnace, burner and heat requirements in the residential sector.

10. Generally improve maintenance and performance standards of furnaces and boilers in the commercial sector, plus increase the use of heat recovery systems.

11. Improve design of all heating and cooling equipment using optimum insulation, modern heat exchange design and heat recovery devices.

12. Develop and introduce large-scale public information and educational programs for the homeowner in order to achieve sound conservation practices in home "operation", plus training programs for maintenance and operation of commercial heating and cooling plant. This will have to be implemented largely by government sponsorship although the private sector in the U.S. has shown some remarkable initiative, for example, the Carolina Power and Light Company has a comprehensive training and educational program for energy conservation (App. D, no. 21).

Mid-Term Measures 1980–1985 (Residential and Commercial)

1. Extend and intensify all short-term techniques.

2. Use integrated design, total energy systems and district heating for commercial and multi-family dwellings. This can be implemented by incentives to municipalities and through tax and other incentives for application of total energy systems. Locational determinants will have to be organized to take advantage of waste heat use and recovery on a large scale.

3. Broadly expand building codes and legislative and regulative devices to establish high standards of conservation.

4. Encourage use of cold water detergents so as to reduce hot water requirements.

5. Extend equipment and appliance design standards for even more enhanced efficiencies through regulative and legislative techniques.

6. Develop R & D programs for durable automatic on-off switches on lights, refrigerators, heaters, air-conditioners, etc.; develop a new fluorescent lamp that is interchangeable with present incandescent types while prohibiting, through building codes, certain uses of incandescent lighting, as well as excessive illumination; establish codes for amount of window or glass in commercial and industrial buildings.

7. Advance official time by one hour in winter and two hours in summer. This can achieve a 1 per cent saving in the entire Residential-Commercial sector by 1985 (App. D, no. 1).

Long-Term Measures 1985–1995 (Residential and Commercial)

1. Implement all short- and mid-term measures effectively.
2. Broadly apply integrated design, total energy systems, utilization of waste heat.
3. Establish total energy systems defining consumption for specific size of dwelling or commercial building through design standards and rationing.
4. Encourage replacement of poorly designed buildings through property tax incentives in an efficient system.
5. Increase support of R & D and management studies in the conservation institute.
6. Increase the use of garbage and coal-in-oil as fuels.

As may be seen from our summary analysis for this sector (Table 1), a 31 per cent sectoral saving in energy can be achieved by 1995. The old populations are affected in both sectors mainly through incentives to replace either entire buildings or heating and cooling systems with the most efficient technology available.

C. Electrical Utilities

We have chosen to include electrical utilities as a sector despite inconsistencies between it and the other secondary consuming sectors, because potential savings are significant and because all the major studies of energy conservation have included it. The per cent savings in this sector are not the result of independent calculations following the methodology used for the consuming sectors. They are rather derived from "consensus" estimates noted in other studies. However their accuracy may in part be supported by the actual reported savings experienced during the energy shortage in the winter of 1974.

Table 3 in Appendix C illustrates Energy, Mines & Resources' projected energy patterns of the electrical utility industry. Despite EMR's projection, several studies indicate that demand elasticities for price, environmental controls, etc., could be negative and the tacit assumptions of the "double-ten" projection (i.e., energy consumption will double every 10 years) may, in fact, be overestimated (App. D, no. 16). On the other hand, if the movement away from labour-intensive industry, now discernable in the U.S. through computer assisted models, applies to Canada then this creates pressures for greater electrical energy consumption.[10] This, however, is clearly at the expense of employment. If this analysis is sound then a specific choice of particular kinds of economic growth in the goods and service mix can be used to optimize energy consumption and employment. The impacts of certain kinds of product choice can optimize both conservation and employment. This is true, for example, for cheese as a protein source over meat products, fluid milk or fish.

10. Bruce Hannon, *Options for Energy Conservation*, Center for Advanced Computation, University of Illinois, Urbana, Ill., Document No. 79, February 1973.

As we have stated, the utilities are not the final consumers of their energy but are converters and distributors. As in the case of transportation where certain modes require liquid fuels, electrical energy is often used for purposes that at present cannot be satisfied in any other way, for example, communications, illumination, cooking. But where space heating derives from thermally generated electrical energy instead of directly from the oil or gas, then the primary energy consumption is increased by a factor of two. If and when nuclear generation is widespread, electrical heat may well be desirable. Also regions where hydroelectricity is the major energy supply may have a case for electrical space heating.

In our conservation analysis of electrical utilities as a sector we are not including waste heat utilization. This use appears as a savings measure in the Residential-Commercial and General Industry sectors. Rather in this sector we are concerned with two basic conservation measures: (1) improved technology of generation, and (2) decreasing demand by an actual gross reduction, by pricing and by smoothing out daily demand cycles. Peaking loads lower the overall efficiency of a generating plant. Table 1 in App. C shows summaries of savings in this sector with populations affected and efficiencies that are realizable. The measures, particularly the social techniques, apply generally to both new and old plants while new technologies which are essentially mid to long term apply largely to future plants. The following is the detailed description of the various recommended measures by term.

Short-Term Measures 1975–1980 (Electrical Utilities Sector)

1. Smooth out daily demand cycle by shifting heavy loads to off peak hours. This can be implemented by restructuring rates for heavy users and excluding certain heavy users from peak hour use by regulation. A problem would be to avoid too much of a shift of people in industry to off peak hours. But this would be partially overcome by applying the measures to the most automated industries first.

2. Facilitate new construction and alleviate construction delays. Here we would be replacing inefficient old plants with more efficient modern plants. This will require a high level of planning within large regions including the organization of continuity of equipment supply.

3. Effect educational and information programs. These have been discussed before and are essential in achieving conservation.

4. Revise siting and planning procedures of new plants of all types by using open hearings with complete access to information in the public interest to maximize citizen participation.

Mid-Term Measures 1980–1985 (Electrical Utilities)

1. Continue to expand all short-term measures, particularly reduced demand measures.

2. Assist development of total energy systems with central power generation, thus increasing the use of waste heat. This is similar to

savings in other sectors but could also reduce electrical consumption. Develop "thermal storage" facilities for off-peak times.

3. Encourage consumer education, information and motivation to reduce electrical consumption (examples were given leading to savings in the Residential-Commercial sector, but which would also reduce electrical demand).

4. Encourage system inter-ties and "thermal storage" facilities for off-peak use.

5. Begin an active R & D program for mid- and long-range improvement of generating efficiency. Some of this technology is already available, for example, combined gas and steam turbine cycle plants, gas-turbine topping plants. Due to Canada's position vis-à-vis natural gas reserves, we should begin this program immediately, although long-term success would depend on the rate of discovery and new production. Natural gas has the additional advantage of being the most environmentally safe fossil fuel. Magneto-hydro dynamics (MHD) with gas-turbine topping units is another R & D program which might be viable for Canada in the long term, in view of our resources (Cesium and Natural Gas) either on our own or on a technology exchange basis with the U.S.S.R. R & D to be effective should commence now.

Long-Term Measures 1985–1995 (Electrical Utilities)

1. Continue to intensify all short- and mid-term programs.

2. Continue R & D on Advanced Power Cycle (combined coal gasification and gas-turbine steam turbine power plants). This in turn depends on an efficient coal gasification process. The recommended Institute for Energy Conservation should begin these programs as soon as possible.

3. Conduct R & D for the requisite metallurgical technology, i.e., metals to withstand extremely high temperatures, also for advanced MHD which can operate at lower temperatures and with a more simplified technology.

4. Support R & D for the further use of waste heat in total energy systems, urban central energy systems, absorption chilling, agricultural and aquacultural applications of waste heat.

It should be noted that the savings through the use of waste heat in the Residential-Commercial and General Industry sectors increase the overall generating efficiency and therefore the savings in the electrical utility sector. Furthermore, the total amount of waste heat projected to 1995 would allow many of the proposed applications to be undertaken. The summary in Table 1 indicates that by 1995 savings of 9.4 per cent could be achieved in this sector.

D. General Industry

Table 2 in Appendix C shows industrial energy consumption and projected growth of demand through the 25-year period under consideration. It is of interest that the sectoral mix of energy consumption in Canada is not the same as in the U.S. either at present or in the future (See Table 8). What is notable is that the energy consumption by the industrial sector in the U.S. is considerably higher and projections maintain this higher fraction. The reverse is true of the Residential-Commercial sector. This probably reflects the more intensive secondary manufacturing in the U.S. and the somewhat higher heating costs in Canada due to climate. The U.S. also has a considerably higher proportion of thermal generation than Canada. Another interesting aspect of the Canadian scene is that the industrial sector is the largest consumer of fuels and will remain so through the mid period. Four industries alone account for between 50 and 55 per cent of all the energy consumed by this sector: the pulp and paper industry (23 per cent of all indsutrial energy in 1972), the chemical industry (particularly "industrial chemical"), the iron and steel industry and the metal smelting and refining industry. Natural gas, primarily, and electricity are projected as the greatest sources of energy for industry.[11] In the U.S.A., primary metal industries followed by chemicals and petroleum refining each use significantly more energy than pulp and paper.

In Canada any substantial improvement in paper making efficiency would have a definite impact on conservation. Two new technologies have been reported. One of these, organic chemical pulping, not only requires less energy but is environmentally superior in that the organic chemical used in the process is recyclable. The new modular newsprint machine also will produce cost and energy efficiencies. The scope for improved efficiencies is of the order of 30 per cent.[12]

By a large-scale introduction of the new type of basic oxygen furnaces in the steel making process, energy savings of 39 to 50 per cent have been reported (App. D, no. 1 and 3). Also, by increasing the amount of scrap iron processed in special furnaces, both energy and materials may be conserved. At present, only about ⅓ of our Canadian steel is produced by the oxygen method. Assuming that by 1995 ⅔ of Canadian steel is using the basic oxygen process, savings should be substantial, a 71.5 per cent increased efficiency over the open-hearth method which now is used in 52 per cent of Canadian processing (App. D, no. 1).

The chemical industry is, of course, an important consumer of energy fuels as feedstock, i.e., for petrochemicals, etc. A major area of saving is indicated by the heavy reliance on process steam in the manufacture of industrial chemicals. Adding process steam to the steam used for heating contributes about 20 per cent of the energy in this sector. By using waste heat to generate steam, savings of 22 per cent have already been realized (e.g., in the Bethlehem Steel plant in Lackawanna as early as 1967 (App. D, no. 1).

11. Energy, Mines & Resources, *An Energy Policy for Canada,* Information Canada, Ottawa, 1973.
12. Private Communication from E.B. Cowan Ltd., Montreal.

By accelerated retirement of old, inefficient processes and equipment, deliberate energy saving design, and upgrading maintenance most industrial and design engineers agree that total sector savings could reach 30 per cent in the long term. Design and systems approach once again are critical as high payoff savings measures. Modular design cuts down on the rate of obsolescence since parts are replaceable. Designing with the end view of reuse and recycling provides significant energy savings while recycling steel and aluminum requires far less energy than the original refining energy. We have already discussed the fact that refillable beverage containers use 25 per cent of the energy for soft drinks and 62 per cent of paper throwaways.[13] This study not only confirmed these energy savings but indicated a 50 per cent dollar saving and a net impact to increased employment. One must be careful in implementing this kind of measure not to place the burden of dislocation on the workers of a particular industry, but to have a master plan for retraining and, if necessary, relocation. Since refillables are more labour intensive it is possible that such dislocations could be avoided.

Recycling automobiles could lead to energy savings amounting to 22 per cent of that used to produce them, as well as conserving materials (App. D, no. 1 and 5). Again proper design and organization are required. Imaginative original design is the necessary component to facilitate recycling.

In a recent poll conducted by McGraw-Hill,[14] 77 per cent of the U.S. corporations polled had enacted corporate energy conservation programs. Many of the companies had achieved significant savings, often as high as 20 per cent.

The following are the specific measures by term for energy conservation in the industrial sector.

Short-Term Measures 1975–1980 (General Industry)

1. Develop economic incentives to upgrade processes, accelerate replacement of high energy absorbing equipment, etc.

2. On all new plants, encourage known technologies and design that are energy efficient through a tax incentive (including design for recycling and reuse).

3. Encourage recycling and component reuse by tax incentives, standards and regulations, and preferential purchasing policies.

4. Encourage site location so that waste heat for process steam can be used.

5. Commence R & D on new energy efficient industrial technologies through government research funding such as PAIT, but extended to prototype and commercial installations which have a national and international impact. The world market for energy efficient processes is an obvious area for Canadian development.

13. Bruce Hannon, *op. cit.*

14. *Energy Information*, 1 March 1974, page 3.

Mid-Term Measures 1980–1985 (General Industry)

1. Continue and intensify all short-term measures.

2. Develop further incentives to encourage all new plants to adopt energy efficient processes.

3. Encourage planning of integrated urban-industrial-recreational areas to take advantage of central power systems, utilization of waste heat, etc.

4. Organize through a combination of processes design and locational determinants reuse and recycling of whole or components of plants. Again, there is great need for planning such ventures as "nuplex" well in advance.

5. Convert beverage container industry throughout the country, if possible, to refillables using proper incentives, regulations, etc. Trade unions as well as citizens and trade groups on all these measures should be consulted.

6. Encourage municipality-based, self-sufficient, industrial processes that are energy efficient, such as local newsprint manufacture, local centralized recycling plant, garbage use as a fuel.

Long-Term Measures 1985–1995 and Beyond (General Industry)

1. Continue at an accelerated rate all short- and mid-term measures.

2. Intensify R & D programs for the development of energy efficient industrial processes aided by government funding.

3. Extend a "design for reuse" program to as many industrial products as advantageous.

4. Encourage R & D for innovative technologies to conserve energy.

Table 1 in Appendix C provides the efficiency improvements for each of the three periods. The per cent of population affected is such that sectoral savings of 6.0, 8.0 and 12.0 per cent are realized by the end of each of the three terms. The assumption is that by the long term (1985–1995) the savings will be applied to new populations representing only replacements and additions.

III. The Impact of Design on Conservation

The professional engineer, particularly one involved in industrial design and standards of design, is one of the key figures in this entire issue of energy efficient processes and products. It is of interest that provincial codes for professional engineers, as well as the national iron ring ceremony in Canada, emphasize efficiency as the key to the ethical responsibility of design. There are many definitions of the ethics of design, but those adopted by a Committee appointed by the Office of Scientific and Industrial Research (U.K. 1963) seem particularly appropriate: (1) design is the use of scientific principles, technical information and imagination in the definition of a mechanical structure, plant, process or device to perform pre-specified functions with the *maximum economy and efficiency* (author's italics); and (2) designer's responsibility covers the whole process from conception to the issue of detailed instructions for production and then interest continues throughout the designed life of the product in service.

The critical aspect of these obligations of design and designer is that they are consistent with both conservation and efficiency principles. While we have maintained that people's values and life styles are critical in the success of conservation programs, not enough attention has been paid to developing an alliance with industrial designers to promote sound conservation principles in all aspects of design from products to systems. Added to this is the establishment of standards and regulations to strengthen the efficiency program.

In the summer of 1951, this author was involved in a study of some 200 heat exchangers of all types for W.J. Fraser, design engineers of Dagenham, Essex. This study was based on operational feedback of performance of these heat exchangers already in use in industry and their original design. Almost all of these heat exchangers had been consistently designed with real capacities much greater than required ones. Three different sets of design equations were examined, i.e., those used by the company, those recommended by ASHRAE and ASME (U.S.), and theoretical heat transfer equations with acceptable safety factors. In almost all cases the latter provided a more reasonable design consistent with intended performance. Also, in all cases, the U.S. design led to even more excessive over-design. This experience has been shared by many design engineers and, just in the general area of heat transfer equipment of all kinds in all consuming sectors, there is little doubt that the application of sound technology and design could lead to general savings up to 50 per cent.

A commercial design architect has reported very similar experiences in his field (Appendix D, no. 20). In the design of high rise buildings, Richard G. Stein has pointed out consistent excessive design by as much as a factor of three in the structural design of beam loadings derived from current live-load tables in U.S. standards. The savings possible in cement alone in the U.S. can be computed as amounting to 4 per cent of their total electrical energy budget. By using stainless steel skin for a new office building in Chicago, Stein indicates a saving of 67 per cent in energy (aluminum required 10 times more energy per pound than steel). These same over-design faults are true of illumination in public and office buildings, schools, and factories. The study points out the general tendency to purchase low efficiency heating, lighting, cooking, and air-conditioning equipment because of lower initial cost without any serious cost-benefit analysis over time.

To summarize, sound design concepts consistent with the efficiency and economy standards of the professional designer can lead to significant savings of energy and materials. Engineering societies could do much to influence such energy conservation programs.

IV. Some Further Considerations of Energy Conservation

In several places in this study we have mentioned energy conservation measures which are not directly related to enhanced efficiencies. Several of these deserve more detailed treatment although they may not be fully realizable until the mid or long term due to economic, technological or environmental problems yet to be overcome. Three specific areas fall into this class: (1) the utilizing of garbage as a secondary fuel, (2) the development of 'coal in oil' as a fuel, and (3) the production of methane from organic wastes. It is not intended in this study to detail any of these but to delineate the major possibilities.

Garbage Utilization as a Fuel

On the average, garbage has a calorific value about 25 to 50 per cent of that of heating oil. Fractions such as plastic have a much higher heating value. In terms of steam generation, one pound of garbage can generate about 4.5 pounds of steam (App. D, no. 18). The European experience with garbage incineration to generate steam suggests that one can develop assured markets for heat from an incinerator. It would be preferable to feed this steam to a combined heat-power station rather than use it for seasonal heating alone, i.e., for district heating. Brown (App. D, no. 18) indicated that with a plant price of $1.00 per 10^6 Btu (selling only 50 per cent of the steam generated), the net cost of garbage incineration is only $2.00/ton. At the lower plant price of $0.40 per 10^6 Btu (the cost of a combined heat-power station) the net cost of garbage incineration is $3.50/ton. Total incineration processing costs are about $12.00/ton for large units. These figures suggest that as collection and disposal costs rise, due in large part to the need for more distant land-fill sites, the use of garbage as a secondary or support fuel becomes very interesting. One of the difficulties is the high cost of quality control in garbage incineration, but this can be absorbed as both conventional fuel prices and garbage collection and disposal costs rise. A further impetus to garbage as fuel would develop through control of packaging materials and improved collecting and sorting techniques.

Canada's urban population generates about 3.5 pounds of garbage per person per day. This amounts to about 70 million pounds per day or 12.5 million tons per year. The heating value of this garbage is approximately equivalent to 12.5 million barrels of oil or about 8.5 per cent of Canada's total primary energy consumption in 1970. It has been argued that recycling of solid waste would be more energy efficient than incineration. Possibly the removal of incombustibles for recycling prior to incineration would be a superior process.

Perhaps a more interesting prospect for the utilization of waste as fuel is pyrolysis. This is the destructive distillation and carbonization, or thermal decomposition in the absence of air. Two new systems are Monsanto's Enviro-Chem Systems Inc. "Landgard" method and the Bureau of Mines "Bu Mines" system.[1] Monsanto has a pilot plant in

1. "Pyrolysis of Refuse Gains Ground", *Environmental Science and Technology*, May 1971, p. 310.

operation for pyrolizing 1500 tons/day of municipal refuse. Bu Mines has been working on various solid waste products or trash such as rubber tires or, as they call it, "young coal". Bu Mines takes ordinary municipal trash with glass and cans separated and produces a pyrolysis yield of solid fuel, oil and gas fractions having a heating value of about 10 million Btu/ton.

The "Landgard" system is able to take municipal refuse as it is without prior separation. They claim their operating costs are roughly 2/3 of an incineration system, i.e., about $8.00/ton. This would be competitive with many urban garbage collection and disposal costs.

Coal-in-Oil as a Fuel

The Canadian Combustion Research Laboratory in the Fuels Research Centre, Energy, Mines and Resources, had experimented with a novel combination fuel consisting of a crude oil slurry containing 35 per cent by weight of pulverized coal. Preliminary combustion tests indicate that this fuel produces a flame indistinguishable from oil (App. D, no. 2).

There are at least three very attractive aspects of this novel fuel. First, it would lead directly to the conservation of petroleum and could extend the life-time of our proven oil reserves by 33 per cent in thermal generation and space heating consumption levels.[2] Secondly, this fuel could allow us to extend the use of coal now, without waiting for the longer range and more costly technologies, such as coal gasification or liquefaction. The reason for this is the third advantage, namely, the relatively low environmental impact of coal-in-oil fuel. On the basis of harmful pollutants per pound of fuel, it is close to crude oil. Even on the basis of Btu it produces only 20 per cent more pollutants than crude oil and 35 per cent less than coal.

Methane from Organic Wastes

There have been numerous reports of methane production from organic waste material.[3] When organic wastes are digested by micro-organisms in the absence of air (anaerobic digestion) a gas is produced containing between 70 and 75 per cent methane. It has been reported that ten cubic feet of methane are produced in the digestion of one pound of waste.

At least two successful commercial operations have been reported; one is the Hyperion Sewage Plant serving Greater Los Angeles which sells its methane to a nearby utility. The potential in Canada of localized sources of animal manure, i.e., feedlots, stockyards, producing 1 trillion cubic feet of methane per year would yield about 20 per cent of current production in the U.S., about 50 per cent of Canada's current production and 2 per cent of Canada's proven reserves! This, of course, is a theoretical figure but the major barriers appear social rather than technical.

2. Williams, "When the Well Runs Dry", *Environment*, Vol. 14, No. 5, June 1972, pp. 10-20 and 25-31.
3. *Ibid.*

The second company involved in sewage conversion is Sollinger Industries of Toronto. They have developed a highly innovative process for a combination of high temperature drying of human and animal wastes and methane generation. The methane is used in part to supply the drying energy and the remainder is available for sale. This company has recently received a contract from the Toronto Stockyards to build a plant on its site and use the entire animal waste production of the stockyard.

This type of energy generation falls into a class called biological or biomass energy. A more conventional form is via the route of growing large scale plant crops with high photosynthetic efficiencies and converting the plants to chemical fuels. This kind of development program is relevant for a country like Canada, particularly in the large agricultural belt of the mid-West. Crops would be chosen which do not compete with food production and are in any case more efficient energy converters. Of course, proper incentives would have to be instituted.

V. Discussion of Results

Tables 1, 5 and 6 in Appendix C provide the various summaries of savings by sector and term, by both percentages and absolute quantities. Comparing these data with Table 2, which provides the projected sectoral energy consumption derived by EMR,[1] we may calculate that in the mid and long term we will achieve an annual growth rate reduction of about 1 per cent or a decrease in consumption by the year 2000 of about 20 per cent. This is equivalent to an idealized exponential rate over 25 years of 3.5 per cent. The actual saving calculated for the year 2000 would be 4.1×10^{15} Btu equivalent to 67 per cent of the total projected energy by the electrical utility sector or 90 per cent of the projected demand by the transportation sector.

The major point to be emphasized is that these new growth rates, at about 1 per cent less than the "historical" projection, provide the same net effectiveness of energy use, but with significant savings, e.g., a reduction of 2.40×10^{15} Btu in 1995 (Table 5) or about 15 per cent of that year's projected consumption of 16.2×10^{15} Btu (Table 2). This saving is not at the expense of reduced economic growth, but it is the result of more effective use of energy.

It is of considerable interest that the U.S., in the face of the uncertainty of security and prices of Mid-East oil, has adopted effective conservation measures. On 16 October 1973, William Simon, then Chairman of Nixon's oil policy committee, announced a series of emergency energy conservation measures designed to save 50 per cent of U.S. total oil imports or 3 million barrels per day. Among the list of measures are automobile speeds reduced to 55 mph, lowered thermostats (3° lower in winter), cold water detergent use, mandatory auto tune-ups every six months and increased car pooling for commuters. In terms of total energy consumption this would represent about 18 per cent of the total national oil consumption in 1975, a truly significant saving. Since the measures being recommended in the U.S. are only a fraction of those we have considered in this study, this further reinforces our claim for the viability of this proposal for energy conservation.

It is not only the U.S., but also Canada, which face the danger of real shortages through the threat of cut-off and excessive prices of Mid-East supplies. The Energy Minister, the Honourable Donald Macdonald, confirmed this threat in a statement on 16 October 1973. Moreover, obtaining increased supplies from Venezuela is only a stop gap measure "not of great assistance" during the Middle East oil supply interruption. If we add to this the speech of Mr. V. L. Horte of Toronto, president of Canadian Arctic Gas Study Ltd., presented in Ottawa on 16 December 1973, Canada will be running short of natural gas supplies by 1979. This has recently been confirmed by the National Energy Board and applies equally to oil. Moreover Mr. Horte indicated that an Alaskan and Mackenzie Delta gas pipeline would have a 5 to 6-year delay before coming

1. Energy, Mines & Resources, *An Energy Policy for Canada,* Information Canada, Ottawa, 1973.

on stream. These disclosures support this study's contention that Canada requires a conservation program. The projected natural gas shortage of 15 per cent of expected demand by 1987 (not considering any major new discoveries) supports the proposal that we consider the production of methane from organic wastes, particularly where such wastes are available in large concentrated quantities such as sewage treatment plants and feed lots. This author has been involved in a feasibility study of this process with Sollinger Industries Limited (see p. 56) and is convinced the approach is technically reliable, although more R & D is required. The total system aspect of the "Sollinger process" also produces the additional benefit of reducing the environmental impact of organic wastes while enhancing the capacity of existing over-taxed treatment installations. This in turn reduces the rate of replacement or the extension of existing plant capacity.

It is recognized that most conservation measures recommended in this study involve some social and economic costs. The relative merits of each proposal could be assessed properly only with sound information of costs and benefits for the short and long run, knowledge of the best means of implementation, cost of selected implementation, net total energy balances, identification of which groups will selectively bear the burden of dislocation, establishing the best methods of minimizing social burdens, the relative pay-off of each of the measures, the social problems of dislocation, environmental trade-offs, etc. A general theoretical background for making such assessments is provided in the Section on pp. 31-34. It would not be possible in this study to attempt a detailed assessment covering such a wide range of measures and techniques. But it should be kept in mind that for each of these measures there will be costs that must be borne by society, firms or individuals. The measures are justified only if the net benefits exceed the costs. However, they are justified only if every attempt has been made to optimize employment redistribution, to introduce labour retraining, and to consider other ameliorations for those who would otherwise bear the entire cost of a social and economic disruption arising from a particular conservation measure. A further qualification is that the conservation measures should be related to the type of fuel saved, i.e., its supply position, substitution possibilities and the impact of regional differences.

A study by the Center for the Biology of Human Systems[2] indicates that certain avenues are open whereby reduced energy demand can be accomplished with little or no reduction in the provision of goods and services derived from that energy. The study supports some of the contentions of this study, namely, that increased energy efficiency as a means of reducing consumption, need not always lead to reduced economic output. Nevertheless, the study admits that to create an actual consumption cut-back from present levels, industry would have to bear the additional

2. Center for the Biology of Human Systems, *Energy and Employment*, St. Louis, Mo., 63130, Box 1126, 1973.

costs through a reduction in either labour productivity or individual production. The study concludes that such questions are fundamental and ultimately relate to the issue of the viability of the entire economic system. Two of the most striking industrial trends in our economy are the tendency to replace labour with electrical power (to raise productivity) and the rapid growth and high profit character of those industries which use energy least efficiently. In terms of industrial value added, the most inefficient energy users were the lowest group. This appears to be a dilemma in that these are not accidental characteristics but part of the web of our entire economic system. But this seeming dilemma does not deny the objective value of energy savings derived through efficiency.

A paper delivered by Dr. Ronald Doctor of Rand Corporation at the AAAS Conference in February 1974 in San Francisco[3] was in surprising agreement with the quantitative, analytical and judgemental aspects of this study. It represented a summary of 4.5 years of studies at Rand on measures designed to reduce energy demand without any significant social dislocations or disruptions. The anticipated savings projected for the very short range, i.e., immediately available, were, in general, higher than those assumed for the short term in this study. But the most significant conclusion of the Rand studies was that through upgrading efficiency within the framework of existing technology, high pay-off savings could result at little to no social or economic costs. Cases were cited for industry whereby such firms as Dow and Dupont have been able to achieve a 20 per cent energy reduction within 2 years through the application of higher thermal efficiency without any cut-back in production. It was suggested that savings of this order using advanced thermal management were broadly available within the general industrial sector. The conclusion of one of the Rand studies for the State of California is that the application of seven measures applied to four sectors – Transportation, Residential, Commercial and General Industry – could achieve savings of 15 per cent in the very short-term period, an amount equalling the current short-fall.

A dramatic conclusion of the 4.5 year Rand Study was that the 1971 projected U.S. demand for total energy of about 4 per cent growth per year could be reduced to a growth rate of less than half this figure. The electrical demand in California could be reduced from a projected annual increase of 6.7 per cent over the next 30 years to 3.5 per cent. Furthermore, Rand is making these claims on the basis of *no reduction in projected consumption of goods and services and no serious social disruption*. This is precisely the claim of this study, namely, that by choosing conservation measures appropriately, demand can be reduced without reduced productivity. But the Rand Study claims these measures can reduce the historical growth rate in energy consumption over the next 20 years by 50 per cent.

3. Ronald Doctor, "Growth and Energy Demand", paper delivered to the AAAS Conference, San Francisco, 25 February 1974.

The Ford Foundation's Energy Policy Project (App. D, no. 9) lends further credence to the conclusions of the Rand Study. Their "technical fix" scenario or projection also concludes that the "historical" growth rate (approximating the average over the period 1950–1972 as 3.4 per cent per year) can be reduced in the next 25 years to 1.7 per cent per year or half the energy demand of the past 25 years. This "fix" is accomplished mainly through energy-saving measures applied to the various end-use sectors and corresponds in great detail to the findings and methods of this study. However, the total savings achieved by the year 2000 are considerably larger than those suggested by this author and correspond to the Rand Study. While the Ford Study suggests that the major technique for achieving these savings is to have the price of energy reflect its full costs to society, i.e., by pricing, they admit this is not fully proven and not sufficient. They thus recommend changes in government policy such as taxes and subsidies as well as consumer education as further techniques for implementing the saving. They also recommend federal support for energy conservation R & D.

The main advantage of the "technical fix" scenario is the implicit provision of greater flexibility in the choice of energy supply options. Indirectly this means that time has been purchased, an extremely valuable asset in the development of technological strategies. Thus the conclusions of the Ford Study concerning the value of securing conservation through increased efficiencies coincide with those of this study.

As a matter of general information, all the papers dealing with measures designed to reduce energy demand at the 1974 AAAS Conference tended to confirm both the approach and quantitative estimates of savings of this study. Cost effective methods cited in these various papers are among those recommended in this study. One paper,[4] for example, indicated that retro-fitting attic insulation of optimal thickness to existing homes had a cost-effectiveness of 0.45 ((Percentage of Total Energy Saved)/(Cost in Dollars)).

Our discussion concludes with a re-emphasis that our estimate of enhanced efficiencies and their rate of implementation is modest and conservative. For example, all new electrical utilities, solely by employing more efficient technology of combined cycle power plants with high temperature gas turbines, in addition to steam turbines, could increase mid-term generating efficiencies by 15 to 20 per cent over present generators, and by as much as 30 per cent when and if we develop MHD. High temperature gas reactors enhance the efficiency by about 8 per cent over the present generation. An even greater order of increased efficiency is accessible to most of our major industrial processes.

In relation to savings in the various sectors of the Canadian economy, we have illustrated in Appendix B a detailed arithmetic analysis of a series of selected measures. It should be noted that we have

4. R.B. Rosenberg, Institute of Gas Technology, "Energy Usage in the Home — Consumption and Conservation", paper delivered to the AAAS Conference, San Francisco, 1974.

not attempted to quantify all the savings recommended in Chapter II. Thus our general approach is very conservative in our estimate of projected savings. This is possibly why more recent large-scale studies such as Rand, MIT and Ford Foundation, forecast about double the savings estimated in this study by the year 2000. To support the legitimacy of this, a "White Paper" on Energy Conservation released by the U.S. Federal Energy Administration indicates that current energy consumption rates could be cut in half by 1985 through selected mandatory and voluntary measures.[5]

5. "White Paper for Energy Conservation", *Science*, Vol. 186, p. 427, 1 Nov 1974.

VI. Conclusions

In many respects we have pre-empted our conclusions in various sections of this study, as in the analysis of results and in the specific content of earlier sections. To summarize the conclusions, we have stated that through both a supply and demand analysis, Canada should seriously consider the adoption of a national energy conservation and efficiency program. We have indicated that the savings that may be expected are substantial, that they may be achieved without any reduction of our projected economic activity levels, but rather through a decreased energy consumption achieved through enhanced efficiencies. The net overall national saving by 1995 is about 15 per cent of that year's projected energy consumption (standard forecast). Given a serious program of voluntary and mandatory demand management a saving of 30 per cent should be possible by 1995.

When one considers that more than 50 per cent of all the energy supply in Canada is discarded as waste, the above saving becomes even more significant. Furthermore, we have indicated that the major savings in the short and mid term (6.8 and 11.1 per cent) may be achieved through known available measures both technical and social and that the R & D necessary for the long term savings should be easily realizable within that time span. We have also argued that the major barriers to successful implementation of these proposed conservation measures are social rather than technical. This means that the public in general must be consulted, informed, involved, educated, and thus committed to the energy conservation program. The burden and initiative for the development of such public commitment must be assumed by the Federal Government as a decision to undertake this conservation and efficiency program immediately.

We have finally argued that such a conservation program is not in conflict with economic goals or objectives and is neither for nor against "historical" growth. We have gone further and suggested that there are economic benefits both direct and indirect in such a program. Increased efficiencies mean lower production costs, while reduced energy consumption reduces environmental control costs and capital investment, often foreign. Other analysts have gone further and suggested that employment is negatively correlated with energy intensive production and that conservation and reduced consumption could increase employment, a major problem in this and other economically developed countries. We cannot seriously judge the merits of this argument, but believe that they must be seriously examined. In fact, we have recommended that all our tacit assumptions concerning energy consumption be critically re-examined in order to develop the best national energy policy that also allows adaptations as options and conditions change, in other words, a clear, flexible energy policy.

We believe that there will be a continuing energy crunch in Canada for at least the next 25 years, facing us with serious supply discontinuities. This internal crunch is upon us now and is compounded by our relations with the U.S.A., which is facing serious changes in its traditional relationships with major suppliers of petroleum in the Middle East. Nixon's "Project Independence" is an expression of this. It would be naïve for us to ignore the evidence that increased pressure on more liberal access to our energy resources will be made by the U.S. We must judge this, of course, from a number of critical considerations, one of the most significant being an estimate of actual exportable quantities. Recent estimates suggest our developed conventional resources are basically short range (about 10 years) and we are already facing threats to our energy demand needs.

One general comment is that care must be taken in the examination of conservation. For example, in a particular process involving energy conversion or industrial production, maximizing energy efficiency per se may not mean maximizing either total efficiency or productivity or minimizing cost. A higher efficiency may be achieved at times at the expense of an increased burden of maintenance, disruption of production, plant wear, or even an increase in the use of certain materials over others. We should constantly keep in mind that we are dealing with a complex system and view energy as part of this system. The systems approach assumes the purpose to be optimizing the benefits accrued by all the sub-systems and, thus, maximizing the system's "global" efficiency. On the other hand, the same systems approach should lead us to include wherever possible both internal and external costs in our accounting. For example, isolating the trade advantage of selling electricity to the U.S. without accounting for the costs of the enhanced production may turn out to be both economically and environmentally unjustified. Efficiency, as we have argued earlier, must be viewed as much as possible as concerning our whole system. And as we have discussed above, efficiency and conservation should also be viewed as part of a larger system. We should add that attempts to measure savings through enhanced efficiencies are most difficult in the industrial sector, not only because of the privacy and segmentary nature of the sector, but because of the difficulty in quantifying both the actual savings and the time sequence in which they are likely to be implemented.

Finally, we would recommend, as suggested in our detailed analysis of savings that we consider the establishment of an energy research institute which would adopt as one of its major tasks the development and the implementation of conservation and efficiency R & D, both short and long term, taking into account Canada's national and international commitments and consistent with the development of a coherent and flexible national energy policy. Naturally another major part of its program would concern itself with the development of new energy technologies for Canada. The technological strategies involved can only be abetted by the savings achieved through increased efficiencies, since such savings extend lead times for the development of technologies with optimum environmental, social and economic values. In consequence, the changing inventory of social attitudes and behaviour is becoming increasingly adapted to conservation rather than consumption. It could be critical for survival in the uncertain future.

Since the research for this study was completed we have witnessed dramatic changes in the energy scene. Among these were the Mid-East oil embargo of the winter of 1974 and the huge leap in the world price of oil. Many of the recommendations in this study would certainly be made more viable by these changes.

There are serious questions regarding the assumption of a causal relationship between high per capita energy consumption and per capita GNP. One study indicates that other social indicators such as health, education, social cohesion and other life-style indicators are not correlated to per capita energy consumption beyond levels determining the state of being an economically developed nation.[1] Energy conservation in Canada can no longer be treated as a speculation, but should become a significant component of national energy policy. The concept of a "compression" economy[2] in which the waste and non-essentials are systematically de-emphasized in order to preserve essentials appears not only feasible but necessary.

1. A. Mazur and Eugene Rosa, *Science,* Vol. 186, No. 4164, 15 November 1974, p. 607.
2. Oscar Morgenstern (Vienna), *Zeitschrift für Nationale Ökonomie,* as cited in the *New York Times,* 30 Jan 1974, pp. 43, 51.

Appendices

Appendix A – A Mathematical Model for Accumulated Energy Savings

Statement of Problem

A. Let $R(t)$ be the projected rate of energy consumption at time t (measured in years), on the assumption that energy consumption continues to grow by a fixed percentage each year. For purposes of reference, $t = 0$ refers to the year 1973.
Since $dR(t)/dt = kR(t)$ we have the well-known condition of exponential growth: $R(t) = R(0)e^{kt}$, where of course $R(0)$ is the rate of energy consumption in 1973 (at $t = 0$). By comparing the expressions for $R(t + \Delta t)$ and $R(t)$, it is easily seen that

$$R(t + \Delta t) = R(t)\, e^{k \Delta t}. \qquad (1)$$

B. If certain energy conservation measures are implemented over a period of T years, beginning now, it is anticipated that the rate of energy consumption at the end of the period will be reduced by a certain fraction S. The new projected rate of energy consumption at time $t = T$ will then be

$$(1 - S)\, R(T) = (1 - S)\, R(0)\, e^{kT} \qquad (2)$$

C. The question is, what is the total accumulated energy saving during the entire period from $t = 0$ to $t = T$?

Solution

D. Let $\bar{R}(t)$ be the new projected rate of energy consumption at time t, assuming conservation measures have been implemented up to that time. If no further conservation measures are implemented, then the rate of energy consumption at time $t + \Delta t$ will be $\bar{R}(t)e^{k \Delta t}$, as in equation (1) above. However, if additional conservation measures are introduced during the time interval from t to $t + \Delta t$, then the projected rate of energy conservation at time $t + \Delta t$ will be reduced by a certain fraction $S(t, \Delta t)$ which will, in general, depend upon both t and Δt. These considerations give rise to the following equation:

$$\bar{R}(t + \Delta t) = (1 - S(t, \Delta t))\, \bar{R}(t)\, e^{k \Delta t} \qquad (3)$$

where, it must be remembered, the fractional saving is a function of both t and Δt. This fraction $S(t, \Delta t)$ will be referred to as the "economy coefficient" corresponding to the time interval from t to $t + \Delta t$.

E. Of course, $S(t, 0) = 0$ as can be seen by putting $\Delta t = 0$ in equation (3). Thus the Taylor expansion of $S(t, \Delta t)$ yields

$$S(t, \Delta t) = f(t)\, \Delta t + \text{terms involving } (\Delta t)^2 \qquad (4)$$

where $f(t)$ symbolizes the Taylor coefficient $S^1(t, 0)$. (This merely says that, for short time intervals, the economy coefficient is proportional to the length of the time interval – however, the constant of proportionality $f(t)$ may vary over long time intervals).

F. By substituting from equation (4) into equation (3), and using the familiar Taylor expansion for $e^{k \Delta t}$, namely

$$e^{k \Delta t} = 1 + k\Delta t + \text{terms involving } (\Delta t)^2$$

we arrive at the following

$$\bar{R}(t + \Delta t) = \bar{R}(t) + (k - f(t))\, \bar{R}(t)\, \Delta t + \text{terms involving } (\Delta t)^2$$

This gives

$$\frac{\bar{R}(t + \Delta t) - \bar{R}(t)}{\Delta t} = (k - f(t))\, \bar{R}(t) + \text{terms involving } \Delta t$$

so that finally

$$d\bar{R}(t)/dt = (k - f(t))\,\bar{R}t$$

G. This differential equation describes how the projected rate of energy consumption will behave if certain conservation measures are imposed.

Explicitly,

$$\bar{R}(t) = \bar{R}(0)e^{kt} \quad e^{-F(t)}$$

where

$$F(t) = \int_0^t f(u)\,du$$

H. For example, if savings are implemented uniformly over the period from $t = 0$ to $t = T$ (which means that $f(t)$ is a constant, $f(t) = c$) then

$$\bar{R}(t) = \bar{R}(0)\,e^{(k-c)t} \qquad (5)$$

It is interesting to note that uniform implementation corresponds to exponential growth at a suitably reduced rate.

I. To find the total energy savings resulting from a given conservation policy, you simply integrate the rate functions $R(t)$ and $\bar{R}(t)$ from $t = 0$ to $t = T$,

obtaining

$$E = \int_0^T R(t)\,dt = (R(0)/k)(e^{kt} - 1)$$

and

$$\bar{E} = \int_0^T \bar{R}(t)\,dt$$

The total accumulated energy saving over the period is of course $\bar{E} - E$.

J. In the case of uniform implementation, for example, $R(t)$ is given by equation (5) and we have

$$\bar{E} = (R(0)/k-c)(e^{(k-c)t} - 1)$$

assuming, of course, that $\bar{R}(0) = R(0)$. If we express the energy saving as $E - \bar{E} = \propto E$, where $\propto$ is the fractional energy saving over the entire period, we find that

$$\propto = [-k/k-c][e^{(k-c)T} - 1)/(e^{kT} - 1)]$$

where k and c are known, and c reflects the rate at which conservation measures are implemented.

K. In fitting this model to the situation described in paragraph B, where the projected rate of energy consumption is given by expression (2), we see that c must be chosen so that

$$\bar{R}(t) = (1 - S)\,R(0)\,e^{kt}$$

Thus

$$e^{-cT} = 1 - S$$

and

$$c = -1/T \log(1 - S).$$

Mathematically, this is just the same as fitting an exponential curve between two points, but it is interesting to note that it corresponds to uniform implementation of savings.

L. Another possible interpretation for the projection given in expression (2) might suggest itself. It could be argued that S represents the economy coefficient resulting from a policy of uniform implementation over the given period, in which case by setting $\Delta t = T$ we would have $c \Delta t = S$, or $c = S/T$. However, with this choice of c, $\bar{R}(T) \neq (1 - S) R(T)$ because of the dynamics of the situation. Nevertheless if S is sufficiently small, this value for c will be almost identical with the value given above, since

$$\log (1 - S) = -S + S^2/2 + S^3/3 + \ldots .$$

For example, if $S = 0.15$ (representing a 15 per cent reduction in the rate of energy consumption) then $cT = S = 0.15$ by this method whereas $cT = -\log (1 - S) \doteqdot 0.14$ by the previous method.

Appendix B – Analysis of Savings

Detailed Analysis of Savings in the Transportation Sector

Short-Term (1975–1980)

Figures for savings are percentage of annual consumption for transportation sector in 1980.

1. Make 30% of new cars bought during this period smaller cars averaging 30% improvement in fuel economy.* (Assume that, allowing for replacement, 50% of the car population in the 1980s will be post-1975 models)

   (0.30) x (0.50) x (0.30) x (0.49) x 100 — 2.21%

2. Improve engine maintenance and use radial tires on 30% of all cars (average 10% improvement in efficiency).

   (0.30) x (0.10) x (0.49) x 100 — 1.47%

3. Lower maximum highway speeds by 10 m.p.h. (assume 70% of all cars travelling above 60 m.p.h. will reduce speed by 10 m.p.h. Assume 50% of all intercity travel is done above 60 m.p.h.)

   (0.50) x (0.35) x (0.70) x (0.13) x (0.49) x 100 — 0.77%

4. Persuade 10% of urban commuter to carpool. (Discount savings by 35% due to extra miles necessary and poorer fuel economy.)

   (0.10) x (0.194) x (0.417) x (0.65) x 100 — 0.52%

5. Shift 10% of urban city-centre passenger-miles to bus.

   (0.10) x (0.26) x (0.417) x ((8100 – 3700)/8100) x 100 — 0.59%

6. Shift 5% of intercity auto passenger-miles to intercity bus.

   (0.05) x (0.35) x (0.417) x ((3400 – 1600)/3400) x 100 — 0.39%

7. Shift 30% of short-haul domestic civil air-passenger miles (PM) (200-mile journey and under) to intercity bus. (assume: 2.8% total PM are short-haul; 85% of total energy used in air transportation is for passenger travel; 50% of total air transportation energy is domestic and civil; neglect difference in energy use per PM for short and long-haul flights.)

   (0.30) x (0.028) x (0.134) x (0.85) x (0.50) x ((8400 – 1600)/8400) x 100 — 0.04%

8. Persuade 10% of people who now drive urban distances of 2 miles or less to walk (assume 9% of PM are in journeys ≤ 2 miles; assume same energy use per PM regardless of journey length).

   (0.25) x (0.09) x (0.65) x (0.417) x 100 — 0.24%

Total Short-Term Saving — *6.2%*

Mid-Term (1980–1985)

Figures for saving are percentage of annual consumption for transportation in the year 1985.

1. Make 50% of new cars average a 30% improvement in fuel economy. (Assume that, allowing for replacement, all of the

* The U.S. Federal Energy Administration is calling for a 40% improvement in fuel consumption for new cars by 1979.

car population in 1985 will be post-1975 models.)

(0.50) x (0.30) x (0.453) x 100 — 6.80%

2. As short-term no. 2 except assume 50% of new cars affected — 2.25%

3. As short-term no. 3 — 0.75%

4. As short-term no. 4, applied to 10% of urban commuters. — 0.49%

5. Shift 20% of urban city-centre passengers-miles to bus. — 1.09%

6. Shift 20% of intercity auto passenger-miles to an equal distribution between intercity bus and rail.

Bus: (0.20) x (0.35) x (0.385) x (0.50) x ((3400–1600)/3400) x 100 — 0.72%

Rail: (0.20) x (0.35) x (0.385) x (0.50) x ((3400–2900)/3400) x 100 — 0.20%

7. As short-term no. 7 — 0.05%

8. As short-term no. 8 — 0.22%

9. Shift 20% of intercity trucking to rail freight

(0.20) x (0.143) x ((3344–670)/3344) x 100 — 2.28%

10. Shift 10% domestic civil air freight to rail (assume 50% total air transportation energy is domestic and civil; 15% total air transportation energy is used for cargo transport).

(0.10) x (0.15) x (0.50) x (0.166) x ((4200–670)/4200) x 100 — 0.10%

11. Improvements in engine and car-body design, in 30% of new cars bought since 1980, giving average fuel economy of 25% (assume that 50% of car population in 1985 will be post-1980 models).

(0.30) x (0.25) x (0.50) x (0.453) x 100 — 1.68%

Total Mid-Term Saving — *16.66%*

Long-term (1985–1995)

Figures for saving are percentage of annual consumption for transportation in the year 1995.

1. As mid-term no. 1 — 5.6%
2. As short-term no. 2 — 1.86%
3. As short-term no. 3 — 0.60%
4. As mid-term no. 4, except apply to 15% of urban commuters — 0.60%
5. Shift 30% of urban city-centre passenger-miles to bus — 1.36%
6. As mid-term no. 6 — Bus: 0.60%; Rail: 0.16%
7. As short-term no. 7 — 0.07%
8. As short-term no. 8 — 0.19%
9. As mid-term no. 9 — 2.46%
10. As mid-term no. 10 — 0.14%
11. As mid-term no. 11, but apply to 50% of new cars. Assume by 1995 all cars will be post-1985 models. — 4.70%
12. Improve engine efficiency for 50% of all highway traffic other than autos. Assume 30% increased fuel economy.

(0.50) x (0.30) x (0.29) x 100 — 0.45%

Total Long-term Saving — *18.23%*

Detailed Analysis of Savings in the Residential Sector

Short-term (1975–1980)

Figures are Btu saved per annum in 1980. The division of sectoral consumption by end-use is based on U.S. data.

	Assumed Consumption as % Res. Sector	Saving Btu x 10^{12}
1. Improved efficiency in space heating and cooling by 20% by enhanced thermal insulation	70%	
(a) applied to 60% new dwellings		
(0.60) x (0.70) x (0.20) x (1.33–1.20) x 10^{15}		10.9
(b) 10% old dwellings		
(0.10) x (0.70) x (0.20) x (1.20) x 10^{15}		16.8
2. Reduced air infiltration, and increased furnace efficiency (by maintenance) leading to 15% reduction in energy use for space heating and cooling, applied to 20% of total population	70%	
(0.20) x (0.70) x (0.15) x (1.33) x 10^{15}		27.9
3. Lower (winter) or raise (summer) thermostat by 3° C, 24 hours daily. Apply to 20% total population, assume 9% reduction in fuel use for space heating/cooling	70%	
(0.20) x (0.70) x (0.09) x (1.33) x 10^{15}		16.8
4. Improved efficiency of hot water heating (including maintenance, insulation, lower water temperature, etc.) Assume 30% increased efficiency for new population, 20% for old	12%	
(a) applied to 60% new population		
(0.60) x (0.12) x (0.30) x (0.13) x 10^{15}		2.8
(b) 10% old population		
(0.10) x (0.12) x (0.20) x (1.20) x 10^{15}		2.8
5. Decreased illumination levels, leading to 20% increase in fuel economy.	1%	
(a) applied to 40% new dwellings		
(0.40) x (0.01) x (0.20) x (0.13) x 10^{15}		0.1
(b) 10% old dwellings		
(0.10) x (0.01) x (0.20) x (1.20) x 10^{15}		0.2
6. Improved efficiency of window-type air conditioning equipment by 20%	6%	
(a) 60% new population		
(0.60) x (0.06) x (0.20) x (0.13) x 10^{15}		0.9
(b) 5% old population		
(0.05) x (0.06) x (0.20) x (1.20) x 10^{15}		0.7
7. Improved efficiency of other appliances by 10%	12%	
(a) 60% new population		
(0.60) x (0.12) x (0.10) x (0.13) x 10^{15}		0.9
(b) 5% old population		
(0.05) x (0.12) x (0.10) x (1.20) x 10^{15}		0.7
Total Short-term Savings		*81.5 x 10^{12} Btu*
Per cent Sectoral Saving	*6.1%*	

Mid-term (1980–1985)

Figures are Btu saved per annum in 1985. Division of consumption by end-use assumed to be unchanged.

	Saving Btu x 10^{12}
1. As short-term no. 1, but improve efficiency by 30%.	
(a) applied to 70% new dwellings since 1980	
$(0.70) \times (0.70) \times (0.30) \times (1.45 - 1.33) \times 10^{15}$	17.6
(b) applied to additional 10% old (pre-1975) dwellings	
$(0.10) \times (0.70) \times (0.30) \times (1.20) \times 10^{15}$	25.2
2. As short-term no. 2	
(a) applied to 30% new dwellings since 1980	
$(0.30) \times (0.70) \times (0.15) \times (0.12) \times 10^{15}$	3.8
(b) applied to additional 10% of pre-1980 population	
$(0.10) \times (0.70) \times (0.15) \times (1.33) \times 10^{15}$	14.0
(These two measures when added to those of the short-term mean that 30% of the total population is affected by 1985)	
3. As short-term no. 3	
Applied to 20% new population and another 10% of old population	
$(0.20) \times (0.70) \times (0.09) \times (0.12) \times 10^{15} + (0.10) \times (0.70) \times (0.09) \times (1.85) \times 10^{15}$	10.6
4. As short-term no. 4, but assume 30% increased efficiency	
(a) applied to 70% new population since 1980	
$(0.70) \times (0.12) \times (0.30) \times (0.12) \times 10^{15}$	3.0
(b) additional 10% old (pre-1975) population	
$(0.10) \times (0.12) \times (0.30) \times (1.20) \times 10^{15}$	4.3
5. As short-term no. 5	
(a)) applied to 40% new (since 1980)	
$(0.40) \times (0.01) \times (0.20) \times (0.12) \times 10^{15}$	0.1
(b) additional 10% old (pre-1975)	
$(0.10) \times (0.01) \times (0.20) \times (1.20) \times 10^{15}$	0.2
6. As short-term no. 6	
(a) applied to 70% new since 1980	
$(0.70) \times (0.06) \times (0.20) \times (0.12) \times 10^{15}$	1.0
(b) additional 10% old population (pre-1975)	
$(0.10) \times (0.06) \times (0.20) \times (1.20) \times 10^{15}$	1.4
7. As short-term no. 7	
(a) applied to 70% new (since 1980)	
$(0.70) \times (0.12) \times (0.10) \times (0.12) \times 10^{15}$	1.0
((b) additional 10% old (pre-1975)	
$(0.10) \times (0.12) \times (0.10) \times (1.20) \times 10^{15}$	1.4
All Short-term Measures	*81.5*
Total Mid-term Savings	*165.1 x 10^{12} Btu*
Per cent Sectoral Saving	*10.1%*

Long-term (1985–1995)

Figures are Btu saved per annum in 1995. Division of consumption by end-use assumed unchanged.

	Saving Btu x 10^{12}
1. As mid-term no. 1	
(a) applied to 70% new (since 1985)	
(0.70) x (0.70) x (0.30) x (1.87–1.45) x 10^{15}	61.7
(b) additional 10% old (pre-1975)	
(0.10) x (0.70) x (0.30) x (1.20) x 10^{15}	25.2
2. As short-term no. 2	
Applied to 30% new (since 1985)	13.2
3. As short-term no. 3	
Applied to another 10% of total population	
(0.10) x (0.70) x (0.09) x (1.87) x 10^{15}	11.8
4. As mid-term no. 4	
(a) applied to 70% new (since 1985)	10.6
(b) additional 10% old (pre-1975)	4.3
5. As short-term no. 5	
(a) applied to 40% new (since 1985)	0.3
(b) additional 10% old (pre-1975)	0.2
6. As short-term no. 6, but assume 30% increased efficiency	
(a) applied to 70% new (since 1985)	5.3
(b) additional 10% old (pre-1975)	2.2
7. As short-term no. 7, but assume 20% increased efficiency	
(a) applied to 70% new (since 1985)	7.1
(b) additional 10% old (pre-1975)	2.9
Short- and Mid-term Measures	*165.1*
Total Long-term Savings	*319.9 x 10^{12} Btu*
Per cent Sectoral Saving	*16.7%*

Detailed Analysis of Savings in the Commercial Sector

Figures refer to savings per annum by the end of the term considered.

	Savings 10^{12} Btu
Short-term (1975–1980)	
Overall improvements in efficiency	
(a) 25% improvement in efficiency, applied to 25% new population.	
(0.25) x (0.25) x (0.50) x 10^{15}	45.0
(b) 15% improvement in efficiency, applied to 20% old population.	
(0.20) x (0.15) x (1.19) x 10^{15}	25.0
Total Savings	*70.0 x 10^{12} Btu*
Per cent Sectoral Savings	*4.1%*

Mid-term (1980–1985)

Overall improvements

(a) 35% improvement in efficiency, applied to 30% new (since

1980) population

(0.30) x (0.35) x (0.56) x 10^{15} — 58.8

(b) 15% improvement in efficiency, applied to additional 10% old (pre-1975) population.

(0.10) x (0.15) x (1.19) x 10^{15} — 17.9

Short-term Measures	*70.0*
Total Mid-term Savings	*147.0 x 10^{12} Btu*
Per cent Sectoral Savings	*6.5%*

Long-term (1985–1995)

Overall improvements

(a) 40% improvement in efficiency, applied to 50% new (since 1985) population.

(0.40) x (0.50) x (1.46) x 10^{15} — 292

(b) 20% improvement in efficiency, applied to additional 20% old (pre-1975) population.

(0.20)x (0.20) x (1.19) x 10^{15} — 47.6

Short- and Mid-term Measures	*147.0*
Total Long-term Savings	*486.6 x 10^{12} Btu*
Per cent Sectoral Savings	*13.1%*

Detailed Analysis of Savings in the General Industrial Sector

Figures refer to savings per annum by the end of the term considered. (Suggested savings in this sector are extremely speculative)

	Per cent Sectoral Saving	*Saving Btu x 10^{12}*
Short-term		
Overall improvements in efficiency, allowing 20% reduction in energy consumption, by 30% of population.	6.0%	
(0.20) x (0.30) x (2.06) x 10^{15}		124.8
Mid-term		
Overall improvements allowing 20% reduction in energy consumption, by 40% of population.	8.0%	
(0.20) x (0.40) x (2.60) x 10^{15}		205.2
Long-term		
Overall improvements allowing 30% reduction in consumption by 40% of population.	12.0%	
(0.30) x (0.40) x (3.63) x 10^{15}		432.8
Total Savings		762.8

Appendix C – Tables

Table 1 – Summary of Actual and Percentage Savings by Sector and Term

	Sectoral saving percentage	consumption[b] 10^{15} Btu	saving 10^{12} Btu
Short-term			
Transportation	6.2	2.09	130
Residential	6.1	1.33	81
Commercial	4.1	1.69	69
General Industry	6.0	2.06	124
Total secondary demand[a]		8.20	
Electrical Utilities	3.5	2.85	89
Total Savings	*6.0*		*493*
Medium-term			
Transportation	16.7	2.50	416
Residential	10.1	1.45	165
Commercial	6.5	2.25	147
General Industry	8.0	2.60	200
Total secondary demand[a]		10.60	
Electrical Utilities	7.8	3.40	270
Total Savings	*11.3*		*1198*
Long-term			
Transportation	18.2	3.70	673
Residential	16.7	1.87	312
Commercial	13.1	3.71	487
General Industry	12.0	3.63	436
Total secondary demand[a]		16.20	
Electrical Utilities	9.4	5.17	485
Total Savings	*14.8*		*2393*

[a] Not total of above; Secondary energy plus transformation losses equals primary energy.
[b] from Table 2

Table 2 – Projections of Energy Consumption by Sector and Period (in Btu $\times 10^{15}$)

	1975	1980	1985	1990	1995	2000
Transportation	1.55	2.09	2.50	3.09	3.70	4.47
Residential	1.20	1.33	1.45	1.63	1.87	2.10
Commercial	1.19	1.69	2.25	3.03	3.71	4.49
General Industry	1.70	2.06	2.60	3.05	3.63	4.20
Total secondary demand[a]	6.70	8.20	10.60	13.10	16.20	20.23
Electrical Utilities	2.24	2.85	3.40		5.17	5.97

[a] Not total of above; also not identical to total in "Standard" forecast but calculated as ideal exponential growth to a total of 20.2×10^{15} Btu for the year 2000. Secondary energy plus transformation losses equals primary energy.

Source: Energy, Mines & Resources, *An Energy Policy for Canada,* Information Canada, Ottawa, 1973.

Table 3 – Electrical Utility Energy Consumption (in Btu $\times 10^{15}$)

	1975	1980	1985	1995	2000
Hydro (used)	1.93	2.33	2.61	2.96	3.12
Thermal (used)	0.31	0.52	0.79	2.21	2.85
Total	*2.24*	*2.85*	*3.40*	*5.17*	*5.97*
Waste heat (from thermal generation only)	0.74	1.29	1.46	4.12	5.30

Sources: Energy, Mines & Resources, *An Energy Policy for Canada,* Information Canada, Ottawa, 1973, and existing generating efficiencies.

Energy, Mines & Resources, Canadian Combustion Research Laboratory, *Energy Conversion and Conservation,* by A.C.S. Hayden, Information Canada, 1973.

Table 4 – Index of Projected Energy Consumption, (base year 1975 = 100)

	1975	1980	1985	1995
Transportation	100	135	161	239
Residential	100	111	121	156
Commercial	100	142	189	312
General Industry	100	121	153	214
Electrical Utilities	100	124	153	232

Source: Table 2

Table 5 – Summary of Actual Savings by Sector and Term (in Btu × 10^{15})

Sector	Short Term 1980	Mid Term 1985	Long Term 1995
Transportation	0.13	0.42	0.67
Residential-Commercial	0.15	0.31	0.80
Electrical Utilities	0.09	0.27	0.49
General Industry	0.12	0.20	0.44
Total Savings	**0.49**	**1.20**	**2.40**
Total Savings as percentage of Total Secondary Demand	5.97	11.32	14.81
New Projected Energy Consumption[a]	7.71	9.40	13.80

[a] Total Secondary Demand minus Total Savings

Table 6 – Energy Consumption by Sector, with Savings (in Btu × 10^{15})

Sector	Short Term	Mid Term	Long Term
Transportation	1.96	2.08	3.03
Residential-Commercial	2.87	3.39	4.78
Electrical Utilities	2.76	3.13	4.68
General Industries	1.94	2.40	3.19
New Projected Energy Consumption[a]	7.71	9.40	13.80
Total Secondary demand (EMR "standard forecast")	8.20	10.60	16.20

[a] represents differences between original projected demand (Table 2) and calculated savings (Table 5).

Table 7 – Efficiency of Various Modes of Transportation

Passenger (Intercity) Mode	Btu/PM[d]	PM/gal
Bus	1600	104[a]
Rail	2900	57[a]
Auto	3400	44[b]
Air	8400	17[c]
Passenger (Urban) Mode	Btu/PM[d]	PM/gal
Mass Transit (other than bus)	4100	
Bus	3700	62[a]
Auto	8100	18[b]
Freignt Mode	Btu/TM[d]	TM/gal
Rail	670	250[a]
Waterway	680	
Truck	3800	
Air	42000	3[c]

Notes: PM = passenger-miles; TM = ton-miles
[a] assuming all diesel fuel and using 35 gallons = 5.83 × 10^6 Btu
[b] using 35 gallons = 5.22 × 10^6 Btu (gasoline)
[c] using 35 gallons = 5.05 × 10^6 Btu (aviation fuel)
[d] US data
Sources: Office of Energy Conservation, Energy, Mines & Resources.
Eric Hirst, "Transportation Energy Use and Conservation Potential", *Science and Public Affairs*, vol. 29(9), pp. 36–42.

Table 8 – Comparison of Sectoral Energy Consumption in Canada and the US in 1971 (percentage)

Sector	Canada	US
Transportation	21	25
Residential-Commercial	29	21
Electrical Utilities	26	25
General Industry	24	29

Note: These figures are not meant to represent distinct uses, since there is overlapping, but they indicate variations in patterns of consumption.

Table 9 – Distribution of Transport Energy Consumption (percentage)

	1975	1980	1985	1995
Road[a]				
Car[b]	50.3	49.0	45.3	37.8
passenger[c]	*42.8*	*41.7*	*38.5*	*32.1*
freight[c]	*7.5*	*7.3*	*6.8*	*5.7*
Other[b]	25.2	26.0	27.0	29.0
intercity trucking[d]		*13.8*	*14.3*	*15.4*
Total, Road	75.5	75.0	72.3	66.8
Rail[a]	5.7	4.9	4.8	4.6
Air[a]	10.8	13.4	16.6	23.0
Marine[a]	7.3	6.7	6.3	6.0

Notes: All figures are percentages of total transportation sector energy use.
[a] Derived from Source 1.
[b] Derived from Source 2.
[c] Assuming passenger transport uses 85 per cent of car energy use
[d] Assuming intercity trucking uses 53 per cent of 'other highway' energy use (derived from Canadian Resourcecon)

Sources: 1) Energy, Mines & Resources, *An Energy Policy for Canada,* Information Canada, Ottawa, 1973.
2) Background Study, *Energy Scenarios for the Future,* by Hedlin Menzies and Associates Limited, forthcoming. Also, a study prepared for the Transportation Development Agency by Canadian Resourcecon in 1973.

Table 10 – Percentage Distribution of Car Passenger-miles and Energy Use for Car Passenger Transport

	Passenger-miles	Energy Use
Urban		
city center	16.4[b]	26.0
commuting	*4.9*[c]	*7.7*
non-commuting	*11.5*	
not city center	24.6	
commuting	*7.4*[c]	*11.7*
non-commuting	*17.2*	
Total, Urban	41.0[a]	65.0[d]
Intercity	59.0	35.0[d]

[a] Source 1.
[b] Assuming 40 per cent of urban passenger miles are in journeys proceeding into city centers
[c] Assuming 30 per cent of urban passenger miles are commuting
[d] Using U.S. efficiency of transportation data from Source 2.

Sources: 1) Study prepared for the Transportation Development Agency by Canadian Resourcecon in 1973.
2) Eric Hirst, "Transportation Energy Use and Conservation Potential", *Science and Public Affairs,* vol. 29(9), pp. 36–42.

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A National Statement by the Faculties of Agriculture and Veterinary Medicine at Canadian Universities, 1975.