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ATOMIC ENERGY OF CANADA LIMITED

L'ÉNERGIE ATOMIQUE DU CANADA LIMITÉE

# SOURCES, AVAILABILITY AND COSTS OF FUTURE ENERGY

by

R. G. Hart

Presented at the
Energy Conservation In Buildings (Old And New) Conference
Saskatoon, Saskatchewan, February 16, 1977

Whiteshell Nuclear Research Establishment
Pinawa, Manitoba, ROE 1LO
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## ABSTRACT

An attempt is made to put the future energy scene in perspective by quantitatively examining energy resources, energy utilization and energy costs. Available data on resources show that conventional oil and gas are in short supply and that alternative energy sources are going to have to replace oil and gas in the not too distant future. Cost/applications assessments indicate that a mix of energy sources are likely to best meet our energy needs of the future. Hydro, nuclear and coal are all practical alternatives for meeting electrical needs and electricity is a practical alternative for space heating. Coal appears to be the most practical alternative for meeting much of the industrial energy need and frontier oil or oil from the tar sands appear to be the most practical alternatives for meeting the transportation need. Solar energy shows promise of meeting some of the space heating load in Canada if economical energy storage systems can be developed. The general conclusion is that the basic energy problem is energy conversion.

Atomic Energy of Canada Limited
Whiteshell Nuclear Research Establishment
Pinawa, Manitoba, ROE 1LO
August, 1977

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# LES SOURCES, LA DISPONIBILITE ET LE COUT DE L'ENERGIE FUTURE

par

R.G. Hart

Présenté à la Conférence sur la conservation de l'énergie
dans les bâtiments (vieux et neufs).
Saskatoon, Saskatchewan, 16 février 1977


## RESUME

On a essayé de mettre le scénario futur de l'énergie dans sa propre perspective en faisant un examen quantitatif des ressources, de l'utilisation et du coût de l'énergie. Les données disponibles relatives aux ressources indiquent que le pétrole et le qaz classiques sont limités et que d'autres sources d'énergie devront remplacer le pétrole et le gaz dans un avenir assez proche. Une évaluation du coût et des applications révèle qu'une combinaison de sources d'énergie conviendra le mieux à nos besoins futurs en énergie. L'énergie hydraulique et nucléaire et le charbon sont des solutions pratiques pour la production d'électricité et l'électricité est un moyen pratique de chauffage de locaux. Il semble que le charbon est la solution la plus pratique de pourvoir à la plus grande partie des besoins en énergie de l'industrie et que le pétrole des régions non-développées ou des sables bitumineux est la solution pratique pour les besoins de transport. L'énergie solaire semble pouvoir apporter une contribution prometteuse au chauffage de locaux au Canada si un système de stockage de l'énergie peut être développé. La conclusion générale indique que le problème de base c'est la conversion de l'énergie.



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## 1. INTRODUCTION

First of all let me say that I am very pleased to have been asked to speak about the very important but also very complex subject of sources, availability and costs of future energy. Although our responsibility in AECL has been the development and application of nuclear energy, we have felt it essential to keep up-to-date on other energy alternatives so that we could put nuclear energy in its proper perspective. It is important that we advise where nuclear energy can best meet our future needs; it is also just as important that we advise where nuclear energy cannot meet our future energy needs. To do this intelligently, we have had to assess as pragmatically as we could other energy alternatives. It is the results of these studies that I want to share with you.

I shall divide this paper into four parts. In the first part, I want to talk about points that emerge very clearly through the details of a quantitative look at energy supply. I shall call these the truisms of energy supply. In the second part, I want to talk about energy resources and indicate which energy resources are likely to have an ephemeral existence and which are likely to be able to meet man's needs for a long time to come. In the third part, I want to talk about energy utilization because I have found that it is only through a study of the end use that one can get a clear picture of energy alternatives for the future. In the fourth part, I want to talk about costs. Many alternatives are technically feasible but the big question is: "Are they economically feasible?"

## 2. SOME TRUISMS OF ENERGY SUPPLY

I have consolidated these truisms under six headings and I shall speak briefly about them in turn.

### (1) The Energy Crisis Is Real

About four years ago, at this same University*, I said that we didn't have an energy resource crisis but we did have an energy conversion crisis. One of my colleagues likes to refer to it as an energy prices crisis. No matter what name you choose, there is a crisis. The crisis results from an imminent decline in the availability of domestic oil and natural gas which supply about three-quarters of our total energy needs, and a steady increase in the price of imports. In the longer term, we face an inevitable depletion of the world's resources of oil and gas. We can use substitutes for oil and gas in many of their current applications and we can recover oil from the tar sands and bring in gas from the Arctic but these alternatives will take time to implement and some of them will be costly. Clearly, we are heading for a period when we will be increasingly dependent on foreign oil with its increasingly deleterious effect on our balance of payments. Just as clearly, we need a plan for moving out of this situation as quickly and economically as possible.

### (2) No One Source Of Energy Will Solve The Problem By Itself

It is disappointing to me that so many experts or so-called experts seem prepared to do a very superficial and qualitative review of the energy problem and then try to convince the decision makers that

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their preferred technology will do it all. For example, for a while it was popular to claim that we didn't need coal, because nuclear energy would be sufficient. Then it became popular to claim that we didn't need nuclear energy, coal would be sufficient. Now the popular theme is that we don't need either coal or nuclear energy, solar energy and wind can do it all. Technically, some of these conclusions are in fact correct; however, for the next few hundred years, at least, they just don't make good economic sense. A reasonable look at the economics of the alternatives quickly reveals that the most economical and the most practical solution to the problem involves a mix of alternatives.

(3) No Source Of Energy Is Completely Benign Or Risk-Free

Even a cursory safety analysis will explode the myth that any of the energy alternatives are completely benign or risk-free. Methods have been developed for assessing risks and analyzing environmental impact quantitatively but they are not yet widely used. As scientists and engineers, we should insist on a quantitative evaluation of the impact and the risks of all of the energy alternatives, and evaluate them on a comparable basis. We simply don't do this now.

(4) Energy Sources Other Than Those In Use Today Can Supply No More Than About 10 Percent Of Our Energy Needs In The Year 2000

New technologies require long induction periods before they start to make a significant impact. Thus, even if energy technologies such as coal gasification, geothermal energy, wind, tidal power, biomass, breeder reactors, solar energy or fusion were demonstrated today to be economically attractive, they could not be introduced at a rate sufficient to make a large contribution to our energy needs by the year 2000. Arnold Cohen, in a recent position paper on solar space heating[1], estimates that, with an active effort, the solar heating industry in the United States could be expanded only at a rate sufficient to provide solar heating to 100 000 buildings a year in 1990 and 600 000 to 2 000 000 buildings a year by 2000. At this rate, only 1 percent to 3 percent of the total United States energy needs could be met by solar home heating by the year 2000. Thus, whether we like it or not, the only options we have for significant substitution before the year 2000 are those that are commercially proven today.

(5) Conservation Can Make An Impact And It Should Be Exercised Wherever Feasible

We waste a lot of energy. This is a throwback to the period when energy, particularly that from oil and gas, was cheap. Clearly, we must eliminate this waste but conservation will not eliminate the need for more energy. Estimates made in both Canada and the United States indicate that conservation can, at best, only reduce the rate of energy growth by about 25 percent unless we wish to drastically change the way we live. No quantitative study that I am aware of indicates that we need to make a drastic change in the way we live. We do have energy resources that can maintain our current life style for many centuries to come; the problem will be one of substitution and conversion.

(6) People Will Have To Pay A Higher Fraction Of Their Income For Energy In The Future Than They Have Had To Pay In The Past

None of the future energy technologies being considered today are as simple as drilling a hole in the ground and pumping out oil. Consequently, it is axiomatic that, even in constant dollars, energy costs will increase. I emphasize constant dollars because I don't think that in real terms, costs will increase as much as people think.

Nevertheless, all viable alternatives involve large capital outlays and the cost of money will contribute more heavily to the cost of energy than it has in the past. These projects will undoubtedly provide extensive employment opportunities so it is extremely important that, whatever the future source of energy, we provide both the hardware and the technology ourselves.

## 3. ENERGY RESOURCES

For this discussion, I will primarily use the unit Q = 1.06 $\times 10^{18}$ kJ ($10^{18}$ Btu). To put the discussion in perspective, the world now uses about 0.2 Q of energy per year(2). However, if all of the world's current population of four billion used the same amount of energy per capita as we do in Canada and the United States, the world would use about 1.3 Q per year. Even though birth control technology is now rather well developed, few estimators claim that the world's population will stabilize at less than ten billion and it is generally accepted that such a population could not live in peace and harmony without a significant levelling of the world's living standard. If we assume that it is levelled up to North American standards, which I think most of us would prefer, we are facing a world energy demand of at least 3 Q per year in the not too distant future. I say at least 3 Q per year because if current trends such as increased pollution control, increased recycle of materials, and increased need to use low-grade resources continue, the demand for energy will increase. In fact, the predictions I've seen seem to average about 6 Q, and some are as high as 10 Q.

Although it is not generally recognized, it is possible to make a reasonable inventory of the world's energy potential. For example, one can use the reasonable hypothesis that all of the oxygen in the earth's atmosphere was generated by photosynthesis and thus arrive at a reasonable estimate of the total amount of energy laid down in fossil deposits. Also one can use both cosmic abundance numbers or measurements of the thermal flux through the earth's crust to determine the average crystal abundance of uranium and thorium. Mooradian[(2)] has used numbers of this type to develop the overview of the world energy potential shown in Table 1.

TABLE 1

Overview Of Total World Energy Potential

| Source | Total Energy Available |
| --- | --- |
| Fossil | 10 000 Q |
| Nuclear Fission | $10^9$ Q[1] |
| Nuclear Fusion | $10^9$ Q[2] |
| Solar | 5230 Q per year[3] |
| Wind | 9 Q per year |
| Hydro | ? |
| Tidal | ? |
| Geothermal | ? |
| Wood | ? |

1 Based on total uranium and thorium within a mile of the earth's surface.

2 Based on total lithium within a mile of the earth's surface.

3 Based on total solar energy intercepted by the planet.

You can see that on this simple basis we have the potential of meeting the requirements of our 3 Q or 6 Q or 10 Q society using virtually any of these sources of energy for some time to come. However, now we come to the question of practicality. In dealing with this question, we must consider questions like - what fraction of the fossil and nuclear fuels exist in concentrations that can be recovered economically, how much of the earth's surface can be covered with solar receptors, how much of the wind energy exists at velocities which make recovery practical, how much of the water and tidal energy exists in areas where the topography permits exploitation, and so on. Some of these questions have, of course, been explored in much greater detail than others. For example, it is now generally considered that coal resources are practical only when they exist in seams over 36 cm thick at depths above 1.2 km[2]. Also, current economic analyses indicate that uranium and thorium resources should be put in the practical category only when they exist in concentrations above 100 μg/g within 2.4 km of the surface[2,3]. Clearly, these definitions will change as the costs of energy alternatives change but, as we will see later, they are not likely to change, at least in constant dollars, in the near to medium future. Definitions of this type have been used to develop the energy picture given in Table 2. This is normally defined as the energy resource picture.

You can now see that, if our estimate of resources is correct, coal and lignite could fuel our current 0.2 Q society for 950 years, but could fuel our 3 Q society for only 63 years. Oil and natural gas could fuel our 0.2 Q society for about 120 years, but could fuel our 3 Q society for only eight years. Hydro electricity could make a significant contribution to a 0.2 Q society but since the world's undeveloped resources are primarily in underdeveloped countries, we must assess its contribution against the 3 Q society and here it will make an important

## TABLE 2

### Practical World Energy Resource Picture

| Source | Energy Content |
|---|---|
| Coal and Lignite[1] | 190 Q |
| Petroleum[1] | 11 Q |
| Natural Gas[1] | 10 Q |
| Tar Sands[1] | 1.7 Q |
| Shale Oil[1] | 1.1 Q |
| Nuclear Fission[2] | $10^6$-$10^8$ Q |
| Nuclear Fusion[3] | $10^6$-$10^8$ Q |
| Solar[4] | 15 Q per year |
| Wind | 0.03-0.6 Q per year |
| Hydro | 0.09 Q per year |
| Tidal | 0.002 Q per year |
| Geothermal (Natural)[5] | 0.002 Q per year |
| Wood | ? |

1 Based on distribution in known geologic formations and the assumption that similar distributions exist in similar geologic formations in the earth's crust.

2 Based on an analytical method developed by Johan Brinck and tested on other metals. Uses concentration distribution in known mining areas and the average concentration in the earth's crust. Assumes use of all the uranium and thorium in breeders. The lower number includes resources in large deposits only; the higher number includes small deposits.

3 Assumes that the amount of energy is limited by availabilty of lithium and that the same fraction is recoverable as for fission fuel.

4 Assumes that it is practical to use 1 percent of the land area.

5 Excludes the as yet unknown potential from pumping water into areas where hot dry rocks exist close to the surface.

contribution but will fall far short of the total need. Tidal and geothermal energy can make important contributions only in localized areas. Of the options listed then we must look to fission, fusion, solar energy or possibly wind to provide energy to the 3 Q, 6 Q or 10 Q society of the future. As we progress from the 0.2 Q society to the 3 Q society, coal will play a significant role but the days of our heavy dependence on oil and gas are limited. These fuels will, of course, play a vital role and have a major economic impact while they are still here.

I shall now introduce the concept of proven resources. For simplicity, I have included categories such as proven, inferred, assured, reasonably assured, prognosticated and so on into this category, so my numbers are not likely to be consistent with other numbers you may see listed as proven. However, for the sake of this paper this doesn't matter because the conclusions are the same. Consequently, I'm going to define proven resources as those which are reasonably well defined by drilling, sampling, and other similar methods. In Table 3 I have repeated some of the resource numbers listed in Table 2 and have added a column headed Reasonably Proven(2).

TABLE 3

Reasonably Proven World Energy Resources

| Resource | Energy Content (Q) | Reasonably Proven (Q) |
|---|---|---|
| Coal and Lignite | 190 | 31 |
| Oil | 11 | 2.4 |
| Natural Gas | 10 | - |
| Nuclear Fission | $10^6 - 10^8$ | 320[1] |
| Nuclear Fusion | $10^6 - 10^8$ | ? |

1 Excludes communist countries as their reserves have not been reported.

Only a very small fraction of the nuclear fuel resources are listed in the reasonably proven column. This is because until about a year ago the price of uranium was not high enough to encourage exploration. There is still no economic incentive to look for thorium or lithium. However, it should be repeated that the total resource is well defined by thermal flux and cosmic abundance methods and it is only the distribution that is in doubt. Even at that, the energy available from the reasonably proven resource, assuming that it is all burned in thorium and uranium breeder cycles, is about 320 Q.

So far we have looked at the world resource picture. Energy is of course an international commodity and certainly over the long term it is the world picture that is likely to dominate. However, for consideration of costs and a national energy strategy, the national resource picture is also important so I will now look at it in the same way I considered the world picture. Table 4 gives the practical resource picture for Canada[(4)]. To put it in context, Canada now uses about 0.008 Q of energy per year.

You can see that the general picture for Canada tends to parallel that for the world. Coal and lignite could fuel Canada's 0.008 Q society for about 300 years but oil and gas from Western Canada could meet that requirement for only 10 to 20 years. Frontier oil and gas resources, if confirmed, could meet our requirements for 140 to 200 years and our tar sands and heavy oil deposits could add another 194. Again it boils down to a question of economics. Both hydro power and tidal power can play a greater role in Canada than they do on the world scene but the cost of further development in these areas in relation to other alternatives may be too high. My very rough estimate indicates that wood might have a significant role, if the economics are right, and work should be done to assess this possibility. In the long term,

TABLE 4

Practical Canadian Energy Resource Picture

| Source | Energy Content | |
|---|---|---|
| Coal and Lignite | 2.4 | Q |
| Western Canada Oil | 0.022 - 0.032 | Q |
| Arctic and NWT Oil | 0.14 - 0.30 | Q |
| East Coast Oil | 0.20 - 0.24 | Q |
| Oil Sands | 1.4 | Q |
| Alberta Heavy Oil | 0.15 | Q |
| Western Canada Gas | 0.057 - 0.131 | Q |
| Arctic and NWT Gas | 0.45 - 0.63 | Q |
| East Coast Gas | 0.33 - 0.43 | Q |
| Nuclear Fission[1] | $6x10^4$ - $6x10^6$ | Q |
| Nuclear Fusion[1] | $6x10^4$ - $6x10^6$ | Q |
| Solar[2] | 0.5 | Q per year |
| Wind[1] | 0.002 - 0.04 | Q per year |
| Hydro | 0.005 | Q per year |
| Tidal[3] | 0.001 | Q per year |
| Geothermal | ? | |
| Wood[4] | ∿ 0.01 | Q per year |

1 Assumes that since Canada has 6.7 percent of the world's land mass it also has 6.7 percent of the world's resources as listed in Table 2.

2 Based on 1 percent of land mass assuming solar insolation at the 49th parallel.

3 Approximately half of the world's tidal power potential exists in the Bay of Fundy area.

4 Rough estimate made in a later section.

Canadians, like people in the rest of the world, will have to look to nuclear fission, nuclear fusion, solar energy or wind to meet most of their energy needs, with solar energy being somewhat more difficult here than in most other countries because of the lower solar insolation at our latitudes. Table 5[4] gives figures for the Canadian scene in terms of proven resources in relation to the estimated resources.

TABLE 5

Reasonably Proven Canadian Energy Resources

| Resource | Energy Content (Q) | Reasonably Proven (Q) |
|---|---|---|
| Coal and Lignite | 2.4 | 0.2 |
| Total Conventional Oil | 0.4 - 0.6 | 0.047 |
| Oil Sands | 1.4 | - |
| Alberta Heavy Oil | 0.15 | - |
| Total Conventional Gas | 0.8 - 1.2 | 0.069 |
| Nuclear Fission | $6x10^4$-$6x10^6$ | 66 |
| Nuclear Fusion | $6x10^4$-$6x10^6$ | 66 |

In this table, the nuclear fission energy value in the reasonably proven column assumes the use of all of the resource in a breeder fuel cycle. If used in this way, it could fuel the 0.008 Q requirement for 8250 years. If used in a conventional natural uranium fuel cycle, it could fuel the 0.008 Q requirement for about 40 years. However again it must be remembered that the total quantity of nuclear fuel in the earth's crust is accurately known; only its distribution needs to be determined by exploration.

Summarizing the resource picture then we can say that on both the world scene and the Canadian scene oil and gas are in short supply and the days of cheap energy from them are drawing quickly to a close. Coal is more abundant and will assume increasing importance over the next few hundred years. However, for the very long term the world will have to depend on nuclear fission, nuclear fusion, solar energy and possibly wind for the bulk of its energy needs. In Canada, conventional oil and gas resources are likely to become depleted more quickly than they will on a world average basis and we will have to depend on frontier oil and gas and/or oil from the tar sands if we want to meet much of our future requirement for liquid fuel domestically.

## 4. ENERGY UTILIZATION

In this part of my presentation, I want to review the distribution of energy use in Canada today. As I indicated earlier, it is only through a consideration of end use that we can get a clear picture of the real alternatives for the future.

The distribution of energy use in Canada today is approximately as shown in Table 6[5]. I don't anticipate that this mix will change very much in the future except as a result of the substitutions I'll deal with later.

TABLE 6

Distribution Of Energy Use In Canada Today (%)

| | |
|---|---|
| Electricity | 15 |
| Space Heating | 25 |
| Industrial (Other Than Electric) | 30 |
| Transportation | 24 |
| Farm Equipment | 4 |
| Other | 2 |

## 5. ALTERNATIVES FOR THE FUTURE

### 5.1 ELECTRICITY (15%)

This is the only sector of our energy requirement not now dependent on oil or gas. Currently, the bulk of our electricity is produced by hydro power with coal and nuclear energy coming increasingly into the picture as economically feasible hydro sites become scarce. Future electricity supply in the country probably will depend primarily on coal or nuclear energy. The choice between them will likely be dictated primarily by economics and the economics will depend primarily on proximity to coal deposits. In Ontario through 1975, the Pickering A nuclear station produced energy at 7.03 mills/kW.h while the Lambton coal-fired station produced energy at 13.26 mills/kW.h(b). Both stations are designed to produce 2000 MW(e) and both were completed at approximately the same time. The effects of inflation and higher interest rates on nuclear power costs can be seen by comparing the Pickering A costs with those for Bruce A which is going into service now and is expected to produce energy at about 11 mills/kW.h, and Pickering B which will go into service over the period 1981 to 1983 and is expected to produce energy at a cost of about 18.5 mills/kW.h. Nevertheless, Ontario Hydro predicted in its submission to the Porter Commission this year that coal-fired generation will remain about 1.4 times as costly as nuclear generation on its system for the predictable future[7]. By contrast, recent cost estimates for coal-fired stations in Alberta indicate that those stations, if built over the same period as Pickering B, would produce energy at a cost of about 19 mills/ kW.h, approximately the same as Pickering B. The difference in the costs of coal-fired generation in the two locations is due almost entirely to the cost of transporting coal. As I mentioned earlier, hydro sites which can be developed economically are becoming scarce, so they cannot be expected to meet a major portion of the incremental demand for electricity. However, to put hydro power into perspective it is generally accepted that, roughly speaking, hydro power will break even with nuclear power if the electricity from the hydro plant is transmitted 800 to 960 km further than that from the nuclear plant.

No other technology is likely to make a major impact on electrical supply for the foreseeable future.

Recent estimates made at our laboratory using the most reliable information we could obtain indicated that the costs of a solar thermo-electric generating station must come down by at least a factor of five before it can produce energy at a cost competitive with nuclear power or coal. A plant near Toronto would require a land area of at least 130 $km^2$ for each 1000 MW of electricity produced and would require an as yet non-existent energy storage system to make it practical. At an Energy Conversion Engineering Conference in Nevada, September, 1976, Solomon Zwerdling[8], in an address summarizing the state of the art on solar thermal electrics, stated that the cost reduction required was at least a factor of four and noted the same limitation. Solar photovoltaic energy is even more costly and recent estimates[9] indicate that cost reductions of 50 to 100 are required to make this technology competitive.

Wind energy is plentiful but our studies indicate that it is not likely to be practical for large-scale electrical generation. At an average wind speed of nineteen kilometres per hour, and there are few places in Canada that have average wind speeds that high, one would require 40 000 windmills, 30 m in diameter, for each 1000 MW of electricity required. Appropriately spaced, so they would not steal wind from one another, they would require an area of about 33 670 $km^2$ (13 000 square miles). Estimates, based on the actual cost of windmills built in Denmark in 1957 with allowances for inflation, indicate a capital cost of about $5000/kW(e) (output, not rated)[9]. Under these conditions, power costs would be in the range of 70 to 100 mills/kW.h excluding the cost of the storage system[9]. In a recent study, Ontario Hydro estimated an energy cost of 90 to 100 mills/kW.h for conditions somewhat more optimistic than those we chose[10].

Wood is a renewable fuel and some preliminary studies have been made on the use of wood to produce electricity. Szego and Kemp of Intertechnology Corporation have calculated that a 1000 MW(e) plant would require an energy forest of about 2600 $km^2$ in the Southern United States[11]. We have done a similar calculation for growth rates appropriate to the area around North Bay, Ontario, and have arrived at an area of about 21 000 $km^2$. Up until now I have been unable to find any information on the cost of harvesting the wood, consequently I have been unable to arrive at an estimate that I can quote with confidence on the potential cost of energy. The pertinent information should be available from pulp and lumber companies and should be collected. However, the areas are so large that, at first glance, the concept does not seem practical for large-scale electricity production.

I have also made some very preliminary calculations on the extent of Canada's wood resources. If we assume that the energy yield and growth rates for the North Bay area represent the average yield for the forested areas of Canada, we find that Canada's forests will produce roughly 0.8 Q or on a renewable basis about 0.01 Q per year. This is a large resource but much more information on costs, the value of the wood for alternative purposes, and ecological effects is required before we can assess its applicability. As we all should recognize, it has application in isolated areas but intuitively I believe that the problems mentioned above will limit its application to these areas.

Tidal and geothermal generation of electricity are practical and will almost certainly be economical in some locations but the areas of application will be limited, and these technologies probably will not play a very significant role in the overall picture. Consequently, I have not attempted to obtain any detailed information on them.

Table 7 summarizes the costs of the various alternatives for the production of electricity. Distribution costs are not included. In all cases I have used costs that are approximately valid for facilities going into service in 1976 and have assumed public utility financing.

TABLE 7

Estimated Costs Of Alternative Methods Of Producing Electricity
(1976) mills/kW.h

| | |
|---|---|
| Hydro (Transmission ∿ 800 kilometres) | ∿ 15 |
| Nuclear | ∿ 11 |
| Coal (Ontario) | ∿ 19 |
| Coal (Alberta) | ∿ 12 |
| Solar Thermo-electric (Without Storage) | ∿ 50 |
| Solar Photovoltaic | ∿ 500 - 1000 |
| Wind (Without Storage) | ∿ 70 - 100 |
| Wood | ? |

We have looked in a general way at the effects of inflation on all of these alternatives and although the effects are likely to differ, the difference probably will be insufficient to change the overall picture. You can see that after the good hydro sites have been developed, coal and nuclear power stations are likely to be the most economical ways of producing electricity with the choice between the two likely to be dictated by proximity to coal supplies. The other alternatives that I have been able to evaluate don't appear to come close.

## 5.2 SPACE HEATING (25%)

Now let us turn to the space heating requirement. If you recall the first table, space heating represents about 25 percent of our energy utilization and this requirement is now met primarily by oil and gas. I will deal with future costs of oil and gas in a subsequent section. In this section, I will concentrate on alternatives to oil and gas for space heating.

We are all aware that electrical energy is now selected for many space heating applications over oil and gas so we must conclude that it is competitive and is clearly a viable alternative. Our analyses show that, under certain assumptions, which I assess as optimistic but certainly not ridiculous, solar energy is competitive with electrical energy for space heating so we must consider solar energy also as a viable alternative[12]. In this section, I want to give you the basis of this solar/electrical comparison then I want to mention briefly heat pumps and district hot water heating from a central station. I'm sure none of us want to go back to shovelling coal or chopping wood, even though it might be good for us, consequently I have not included these in my list of alternatives for this application. If the other alternatives become prohibitively expensive, coal may be reconsidered but I doubt that this will occur and in any event I shall be dealing with the cost of coal in a later section.

I have seen several ways of comparing the costs of solar energy and electricity for space heating but from my point of view it is the customer who eventually will decide on the practicality of any alternative, and we have made our comparison accordingly. We have compared both the initial capital and estimated lifetime costs of an electrically heated home in Winnipeg with those for homes heated 70% by solar energy and 30% by electricity and 100% by solar energy. The 70 percent solar home has a three-day heat storage system while the 100 percent solar home has a summer/ winter storage system. The house requires about 54 000 kW.h of energy each year and has a peak requirement of about 15 kW in mid-January. Our studies show that Winnipeg is one of the more favorable locations in Canada for solar heating because of its low incidence of cloud cover.

The basis of the comparison is as follows:

(1) The electricity to the home is supplied by a nuclear electric generating station that went into service in 1976 and an electrical distribution system built in 1976. The utility borrowed money at 8 percent interest and is amortizing the station and the distribution system over 25 years. The operating and maintenance components of the cost of electricity escalate at 5 percent per year due to inflation. These assumptions result in an electrical rate in 1976 of 21.5 mills/kW.h which is higher than experienced today but is reasonable for the comparison being made.

(2) The homeowner takes out a 25-year mortgage at 9.4 percent to pay for his home. This rate is consistent with the 8 percent rate to the utility and both are generally consistent with a 5 percent rate of inflation.

(3) The solar panels cost $\$54/m^2$ ($\$5/ft^2$), deliver 50 percent of the energy of insolation as useful heat to the house, and last for 25 years. The three-day storage system costs $1700 including plumbing and the summer/winter storage system costs $9000 including plumbing.

(4) If a significant fraction of the space heating load in a region is provided by all electric or 70 percent solar/30 percent electric systems, this would probably distort the electrical system resulting in a reduction in utilization of capital plant. The cost of this reduction would affect the cost of electricity. I will give an estimate of how this distortion might affect the comparison. In this estimate it is assumed that a north/south grid is in operation and the electricity is used in the southern part of the grid for air conditioning in the summer.

Table 8 gives a comparison of the capital and lifetime costs to the homeowner for the three heating concepts. The costs of lighting and other miscellaneous electrical loads are included in the lifetime costs because they are difficult to exclude from the calculations. The capital cost of the heat distribution system is excluded because it is common to all systems.

TABLE 8

Comparison Of Capital And Lifetime Costs ($)
For Electrical And Solar-Heated Houses

| Home | All Electric | 70% Solar/30% Electric | All Solar |
|---|---|---|---|
| Initial Capital | 600 | 6 000 | 13 400 |
| Lifetime Cost | 33 400 | 33 300 | 45 400 |
| Lifetime Cost* | 37 000 | 40 200 | 45 400 |

* Estimates include the effect of reduced capacity on cost of electricity.

You can see that if the assumptions made are valid, solar energy is competitive with and a viable alternative to electricity for space heating. The only way I know of testing the assumptions is to build some solar houses and collect data from them. That seems to be what is being done. One of the critical assumptions is the cost of solar panels. We calculate that, if the solar panels cost $\$108/m^2$ rather than $\$54/m^2$ the capital and lifetime costs of the 70/30 and the all solar systems are $10 200 and $46 500 and $17 600 and $57 500 respectively.

An alternative that appears to me to warrant more attention is electrical heating (and air conditioning) by a heat pump. I'm no expert on heat pumps but engineers whose opinion I value tell me that they are now considering installing heat pumps. The advantage of course is that the heat pump, at least in Southern Ontario, should be able to deliver heat at about half the electrical load of an all-electric system and should be readily convertible into an air conditioning unit in the summer. Short-term storage systems would allow a lot of flexibility for electrical system load levelling. J.A. Horvath of Ontario Hydro has proposed the development of a heat pump particularly suited to Southern Ontario conditions[13]. I am advised that most heat pumps today are designed to be air conditioners first. Apparently it would be better in Canada to have a heat pump designed to be a heater first. Heat pumps now cost $3000 to $5000 depending on capacity and Horvath calculated that the extra cost of the heat pump on a heating/air conditioning system would be paid back in three to seven years through savings in the cost of electricity. Most of my engineers who have looked at the alternatives for the future consider this to be the most attractive.

We have also studied district heating systems assuming that two different types of nuclear unit at the Pickering location supplied 600 MW of thermal energy to a distribution system in the city of Toronto[14]. One of the units was a 706 MW unit which produced only heat. The other unit was a 2200 MW thermal unit equipped with a back-pressure turbine which supplied 706 MW of thermal energy and 438 MW of electricity during on-heat periods, and 640 MW of electricity during off-heat periods. The heating costs from both units are compared with electrical resistance heating costs in Table 9.

TABLE 9

Comparison Of District Heating
With Electrical Resistance Heating

| | Thermal Only | Thermal/ Electric | Electrical Resistance |
|---|---|---|---|
| Reactor Core Size MW(t) | 706 | 2200 | - |
| Thermal Power Supplied MW | 600 | 600 | 600 |
| Overall Energy Utilization % | 85 | 36.6 | 27 |
| System Load Factor % | 35 | 80 | 68 |
| Nuclear Station UEC[(a)] mills/kW.h | 9.2 | 4.4[(b)] | - |
| Pipeline UEC mills/kW.h | 7.9 | 7.9 | - |
| DHS[(c)] Grid UEC mills/kW.h[(d)] | 3 -24 | 3 -24 | - |
| Total UEC | 20.1-41.1 | 15.7-36.7 | 30.1 |

(a) UEC = Unit Energy Cost.

(b) Portion charged to district heating.

(c) DHS = District Heating System.

(d) Low number assumes a few large customers; high number assumes many small customers.

It was assumed that the units were started in 1974, and went into service in 1979. The resistance heating costs were based on 1974 electrical rates escalated at 10 percent per year to 1979. The study showed, as one would expect, that the lower capital cost and better fuel utilization of the thermal-only unit was counter-balanced by its much lower load factor. Consequently, the thermal/electric system showed a slight economic advantage over the thermal-only system. The competitive position of both in relation to resistance heating was dependent on the cost of the hot water distribution system. These already exist in several European cities and district heating is quite extensively used there. However, they do not exist in Canada and it is questionable if they can now be economically installed here in competition with the other available alternatives.

In summarizing the space heating situation, we can conclude that electrical energy is a demonstrated alternative to oil and gas and solar energy is a potential alternative. The electrical alternative can probably be made more economical in most of the heavily populated areas of Canada through the use of heat pumps. Direct district heating using either nuclear- or coal-fired stations to provide the heat is practical but the cost and inconvenience of installing a hot water distribution system will probably restrict its use in Canada.

## 5.3 INDUSTRIAL ENERGY OTHER THAN ELECTRIC (30%)

Table 6 shows that this industrial requirement represents about 30 percent of our energy utilization. In 1974 we made a survey of the use of energy (excluding electricity) in industry[15] and found that about 90 percent of the requirement was for low pressure steam, i.e., steam at about 690 kPa (100 psi) or less. We found that this was required primarily in 20 to 80 MW blocks and is currently provided primarily by oil and gas.

Although the nuclear industry has put a significant effort into the development of small reactors, and has developed small reactor systems for application in space, it has not been able to come up with a concept that appears to be economical for wide-spread industrial use. The only possible way that nuclear energy could now be economically used to meet this requirement is to group a large number of industrial users around a station producing at least 1000 MW thermal and this is not practical for most of our industrial applications.

Consequently, the best practical alternative to meet this need seems to be coal. Coal can be produced at the mine head in Alberta for \$0.28 to \$0.57/GJ (\$0.30 to \$0.60/MBtu)[16] depending on the type of mine, but it costs about \$0.80/GJ (\$0.85/MBtu)[17] in Winnipeg and about \$1.80/GJ (\$1.90/MBtu)[16] in Toronto. It seems axiomatic then that extensive programs on improved methods of transporting coal, perhaps in existing pipelines, and in treating the off-gases from coal combustion, would pay off handsomely for the future. Also, coal needs a competitor to prevent its price from simply following the market price for foreign oil, frontier oil and gas, or synthetic oil and gas. At the moment I don't know what that competitor will be.

In summary then, the alternative for industrial energy is coal.

## 5.4 TRANSPORTATION AND FARM EQUIPMENT (28%)

The transportation and farm equipment requirement is met almost entirely by petroleum products. We do not have a good substitute for petroleum and I'm convinced that in the not too distant future Canada will have to depend on oil recovered from the tar sands. The basis for my statement is a series of studies we did in 1972 which compared the cost of frontier gas, synthetic natural gas from coal gasification, and nuclear-generated hydrogen on a comparable basis[18]. The part of the study we did in some detail was the cost of nuclear-generated hydrogen. I have updated those costs to take account of inflation and have compared them with more recent values we have obtained for the other alternatives in Table 10.

TABLE 10

Comparison Of Estimated Costs For Frontier Gas And Oil[19], Oil From The Tar Sands[20], Coal Gasification[21,22] And Nuclear Hydrogen

| | Estimated Cost $/GJ | Estimated Cost $/MBtu | Estimated Cost $/bbl Oil Equivalent |
|---|---|---|---|
| Frontier Gas and Oil | 2.08 | 2.20 | 13 |
| Oil from the Tar Sands | 2.46 | 2.60 | 15 |
| Coal Gasification | 3.79 | 4.00 | 23 |
| Nuclear Hydrogen* | 5.21 | 5.50 | 32 |

* Assumes electrical cost equivalent to that from Pickering B.

You may wonder why I say we will have to depend on tar sands oil when the estimates for frontier gas and oil are cheaper. The reason is simply that we know the tar sands deposits contain about 700 billion barrels of oil and we expect that approximately half of this will be economically recoverable. If we find extensive oil or gas resources in our frontier areas we should certainly use them; however, we should not neglect the development of the pertinent tar sands technology in the hope that the frontier areas will meet our requirements. There should be enough oil in the tar sands to meet our transportation needs for at least a couple of centuries. Although the cost of oil from the tar sands seems high, this shouldn't cause us serious economic difficulties, particularly if we substitute coal in many of our industrial uses. Many Europeans these days pay twice as much as we do for gasoline and many of them seem to be surviving economically very well.

In summary then we can say that in future our transportation needs could be met by frontier oil or oil from the tar sands, with oil from the tar sands favored because of its known abundance. The other alternatives may come later but the need for them is likely a couple of centuries away.

## 6. CONCLUSION

Perhaps in conclusion I could outline to you my plan for Canada's energy future. It's a pretty simple one and is as follows. Use hydro and nuclear energy to produce electricity and let electrical heating take over the bulk of the space heating load; let coal take over the bulk of the industrial demand wherever it is economical for it to do so; use our conventional oil and gas primarily in our transportation sector and develop tar sands technology to replace conventional oil and gas resources when they are gone.

I do not advocate that such a plan be put into force by legislation or that we should discourage studies of other alternatives. For example, solar energy might prove attractive to carry some of the space-heating load and tidal power could make a significant contribution to the electrical load in Canada if it proves to be economic. However, I believe that we should recognize that the plan I am outlining is a potential solution to our future energy needs and avoid obstructions that prevent it from happening as a result of natural economic forces. In Canada we are fortunate; we have practical energy alternatives. All we need is the common sense to develop them and use them wisely.

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