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ENERGY: A RESOURCE BOOKLET FOR TEACHERS

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By

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ABSTRACT

Three chapters comprise this project. The first chapter deals with the global picture of energy supply and demand, and concludes that other sources of energy must be developed in the next fifty years.

Chapter Two considers a number of alternate sources of energy and examines two sources in particular: (i) Hydrogen and its dependence on electricity, and (ii) Nuclear energy used to produce electricity. Certainly, Ontario has a very viable option to produce electricity by means of nuclear energy.

Home heating can, to some extent, be controlled by the individual, and Chapter Three discusses the operation of a heat pump and its feasibility as a heating device for homes in the Southern Ontario climate.

ACKNOWLEDGEMENTS

During the writing of this project, I greatly benefitted from the knowledge of Dr. Martin W. Johns, without whose patience, time, and insight this project might not have been completed. I also thank Dr. S.M. Najm for his gentle prodding to keep me going and for his valuable advice towards the development of this project as a resource book for teachers. My hearty thanks are also extended to Miss V. Koledin for her invaluable assistance. Not only did she make sure that I was always duly registered as a graduate student at McMaster University, but she also somehow managed to type this project so well in such a short time. I also thank McMaster University for offering this graduate programme of study.

Lastly, I wish to thank my wife and children for their great patience and understanding. Without my family's encouragement and their willingness to bear the extra demands my studies placed upon them, this project would not have been completed.

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INTRODUCTION

This project is written primarily as a resource booklet for secondary school science teachers. Most literature on Energy is written on a level that is not convenient or appropriate for the teacher. Energy is not a new field of scientific study. On the contrary, it is an old and well established field, and one would expect general agreement among the various authors. However, one is struck with the strong and diverse opinions held and vigorously expounded on occasion. But upon closer examination, it is seen that the technical aspects of the various energy topics are in reasonable agreement, and the divergent opinions arise in the proposed solutions to the energy crisis. Excellent student training can result from assignments to do critical reviews of various energy articles, especially those of the energy counter-culture. Articles proclaiming various solutions to the energy crisis appear almost weekly, and these articles must be carefully analyzed. The critical review should let a student realize the relative ease with which data can be manipulated to produce a desired result. Even in serious studies, divergent views often conflict. This project demonstrates as an example how Odell and Hubbert have derived totally different estimates of oil and gas reserves. The student should examine the methods these men employ, and should try to determine which one is the more reasonable.

Many articles written on alternate sources of energy are hyperbole. Seemingly there are many easy solutions. For example, solar energy is hailed by many as the answer to the problem, but few have actually studied all the technical, environmental, economic and climatological aspects of this vast topic. Nuclear power also provokes strong and divergent opinions. Probably no other topic polarizes people as much as nuclear energy. This project treats nuclear energy very favourably. A definite bias is demonstrated here. But the student can read a book such as No Nukes and obtain an entirely different perspective. It is a valuable experience for the student to compare the different views on the same topic.

The comparison of the energy literature can become quite confusing for the student because so many different units are used to express the amounts of energy or power. For example, one source will quote the oil reserves in terms of barrels, whereas another source might state it in Joules, or BTU's, or quads. Wherever possible, this project has used the S.I. units, and energy is expressed in Joules or kilowatt-hours, and power is expressed in Watts. Comparisons are valid only if the same units are used. If conversions in units are necessary, the Appendix is included to facilitate this process.

The literature written on Energy is vast. However, one book that was used extensively for this project is W. Häfele's Energy in a Finite World. This book treats energy from a global perspective, which is often missing in other literature. We may be very concerned about the future economy and lifestyle of Canadians, but the global picture is a much more demanding picture. The Third World is a very important factor that cannot be ignored. We may rejoice in that our energy consumption is decreasing, but if we already consume twelve times as much energy per capita as the Third World person, then a slight reduction in our consumption does not solve the terrible inequity in our world, nor does it alleviate the problems in the Third World countries. They must have their proper share also. There is a good ethical lesson in this to which the student should be exposed.

Exponential growth is also a phenomenon that the student should clearly understand. Numerous examples can be used to demonstrate this very rapid growth. This project uses a number of examples, but the teacher also should use those examples that suit his/her own particular pedagogy. But the student must become aware of the very important consequences of exponential growth.

Chapter Two deals with a number of alternate sources of energy, of which two are described in some detail: (i) Hydrogen and its dependence on an available source of electricity, and (ii) Nuclear energy to produce electricity. Nevertheless, no one alternate source is developed extensively. The project only gives broad outlines of various alternate sources--the student can choose further research and develop his particular choice.

The last chapter investigates the heat pump as a heating device for homes in the Hamilton climate. Students have studied previously the operation of a refirgerator, and the heat pump is an appropriate extension. It also allows the student to collect and tabulate much data, and to make the correct deductions from these data. The graphical analysis of data is an extremely important facet of the student's learning process in science, and a study of energy lends itself very well to this.

In conclusion, this project attempts to aid the teacher in making the student better aware of the energy or fuel crisis and possible solutions to this crisis. The ethical question of our high standard of living at the expense of many other people is also raised so that students may realize that solutions are possible but that they won't be cheap and may even be painful. But there are solutions for which the student should strive. It is hoped that this project may in some way help to instill in the student the desire to develop the proper solutions.

CHAPTER ONE

ENERGY OVERVIEW

I. INTRODUCTION

Energy is a most familiar concept, but very difficult to define. People will talk about the "waste of energy" in bureaucracy, or about an "energetic" child, or a "high energy" food, or "Energy makes the world go around", and William Blake said "Energy is Eternal Delight".

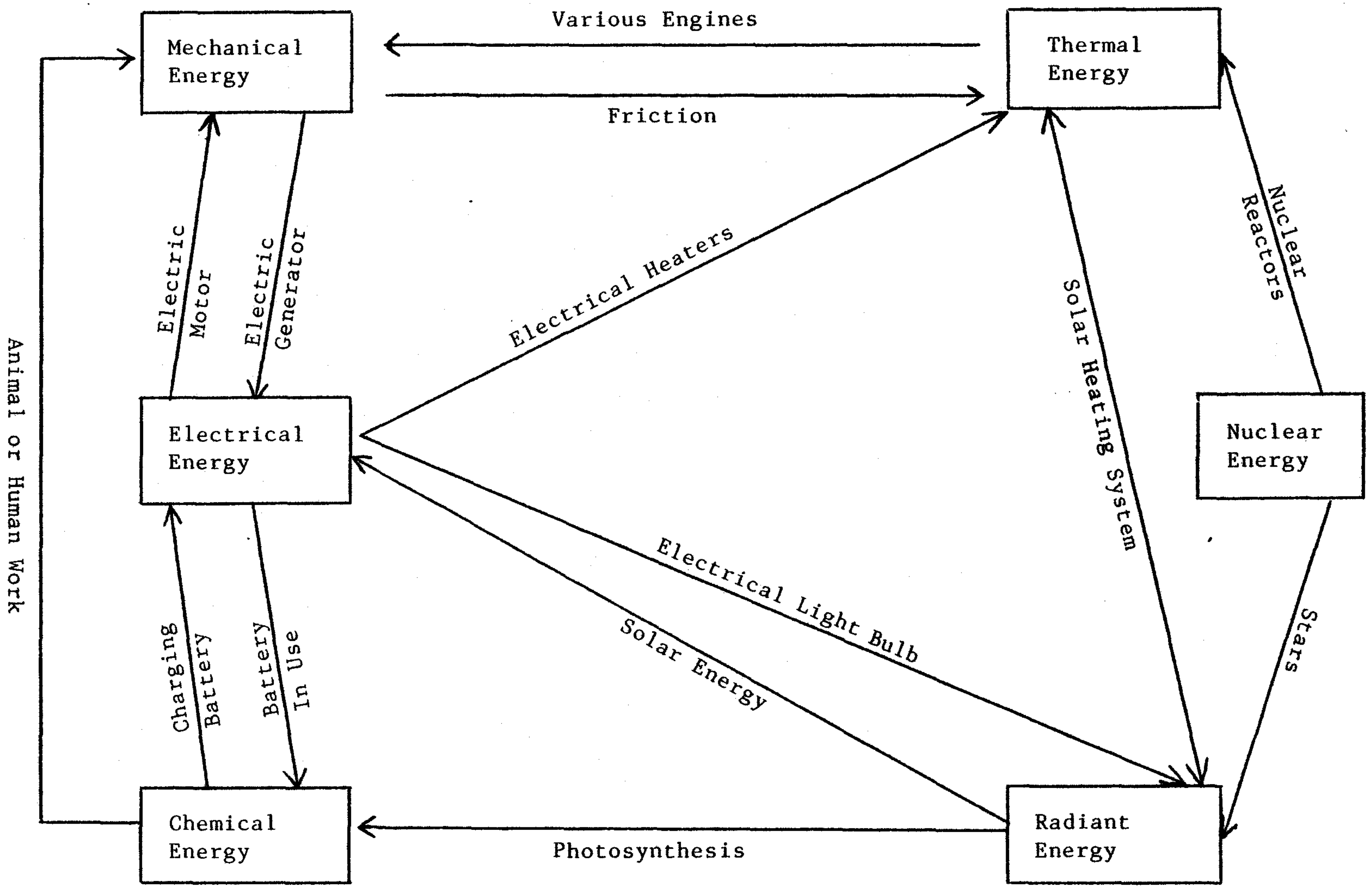
However, to a physicist energy has a very precise definition: the ability to do mechanical work, and work and energy are measured in the same units. The magnitude of a given energy resource is precisely defined in terms of the mechanical work that must be done to create that energy source or the mechanical work that is done when that energy resource is destroyed.

Energy comes in many forms, and conversion from one form to another is in principle always possible; some of the major changes are shown below (see Diagram 1).

However, one of the basic principles underlying all of science is that the total amount of energy in the universe is constant. Indeed, the total energy in any closed system (one that does not interact with its surroundings) is constant and can only be increased by doing work on the system or reduced by making the system do work on something outside the system.

Until the 20th century mass and energy were thought to be independently conserved in the universe. In 1905, Einstein proposed that mass was simply another form of energy, connected to it by the equation $E = mc^2$,

DIAGRAM 1


Mechanical Energy
Thermal Energy
Electrical Energy
Nuclear Energy
Chemical Energy
Radiant Energy
Various Engines
Friction
Electric Motor
Electric Generator
Electrical Heaters
Nuclear Reactors
Solar Heating System
Animal or Human Work
Electrical Light Bulb
Solar Energy
Charging Battery
Battery In Use
Stars
Photosynthesis

where E is energy in Joules, c is the speed of light in metres/second, and m is the mass in kilograms. Einstein's proposition was quickly demonstrated in thousands of nuclear reactions and brought forcefully into the public domain with the explosion of the first atom bomb. The energy yield from mass conversion is so immense that the energy available in only one hundred kilograms of matter would meet the entire Canadian energy demand for one complete year.

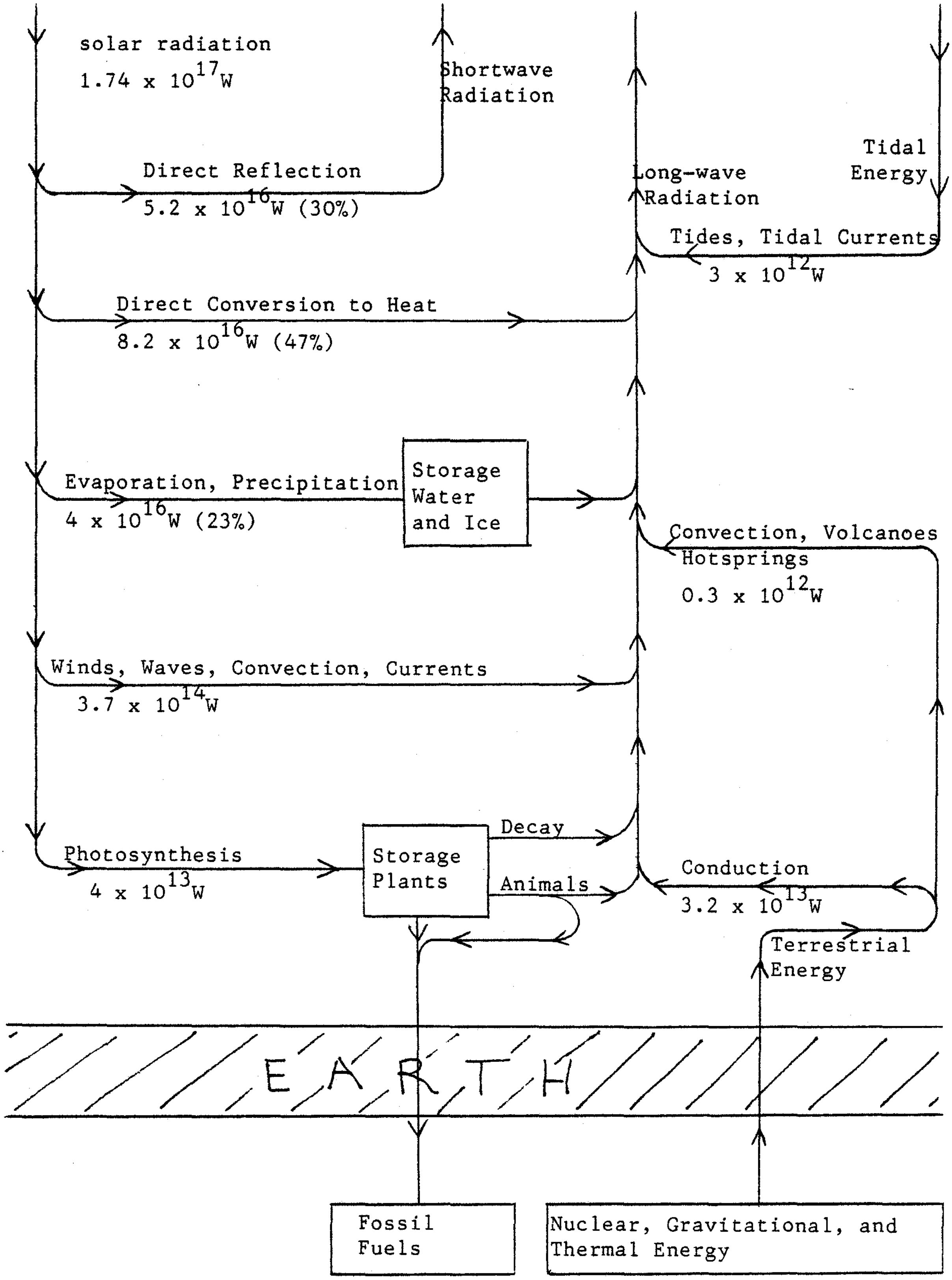
II THE ENERGY BALANCE AND ENERGY FLOWS

The mass-energy conversion accompanying the nuclear reactions that occur within the sun is the source of all solar energy. This energy source is responsible for maintaining a terrestrial climate suitable for life and nurturing all the life on this earth.

For billions of years the earth's annual energy balance sheet has been and still is a little on the plus side, with small amounts of energy being laid away. Each day the sun shone, and plants built energy-rich molecules--more than enough for their own growth and survival into future generations. Much of the remainder was eaten by herbivores which in turn were eaten by carnivores; everything that died furnished food for scavengers and a host of decomposers. There was a surplus of food. Some of it, buried in mud or at the ocean bottom or otherwise protected from decomposition, became available recently when modern man found it as fossil fuels. M.K. Hubbert has summarized the energy flow to and from the earth as follows (see Diagram 2).

More than 99% of the total input energy is solar energy. Of this total, only about 0.02% is trapped by photosynthesis, yet it is from this seemingly insignificant process that the fossil fuels were and are made:

DIAGRAM 2: Energy Flow Sheet for the Earth[1]



coal, oil shale, petroleum, and natural gas. The rate of storing energy as fossil fuels is about the same today as it was in the last 600 million years. However, today's rate of energy consumption is much greater than the rate at which it is stored. Fossil fuels have stored about 5×10^{22}J which is being consumed today at a rate of 4×10^{13}W. Since 1 Watt = 1 Joule/second, this rate corresponds to:

$$4 \times 10^{13} \frac{\text{Joules}}{\text{second}} \times \frac{3600 \text{ seconds}}{1 \text{ hour}} \times \frac{24 \text{ hours}}{1 \text{ day}} \times \frac{365.25 \text{ days}}{1 \text{ year}}$$

$$= 1.3 \times 10^{21} \text{ Joules/year.}$$

If this rate continues unabated, simple arithmetic tells us that the fossil fuel source will be depleted in about 40 years.

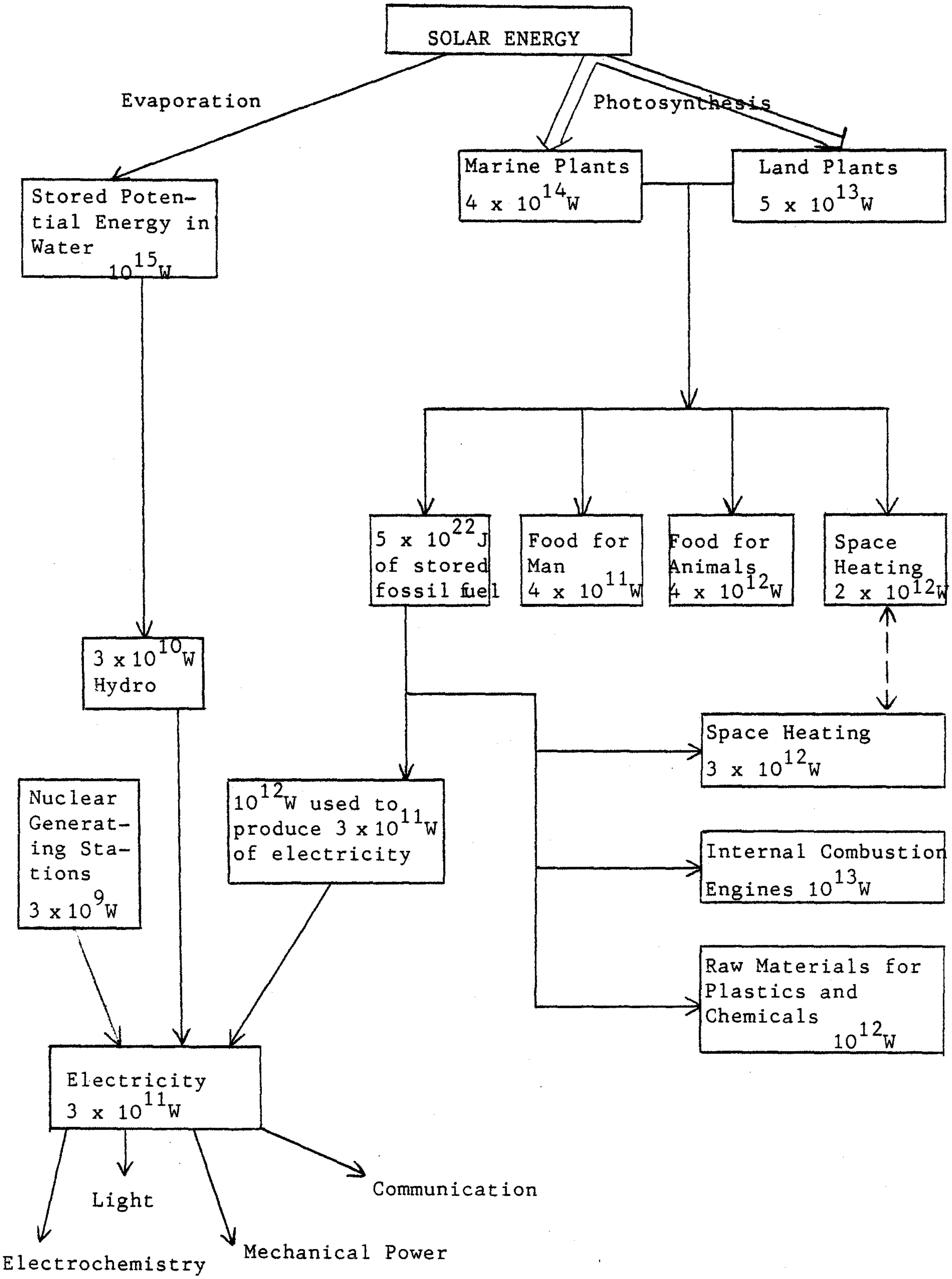
The major energy flows into man's society come from solar energy and fossil fuels with a small contribution from the fission of the uranium found in the earth's crust. These pathways of energy flows are outlined in the following diagram (see Diagram 3).

III ENERGY--A PRACTICAL CONCERN

A. Introduction

Energy is, of course, an immensely practical concern since it is absolutely essential for food growth, and for keeping people alive. "Energy" drives today's modern industrial and technological societies. As energy resources decrease, the quality of food and heating diminishes, as well as transportation, jobs, standards of living, etc. Modern society has expanded ruthlessly without realizing or understanding how utterly dependent society is upon energy. The size and shape of our modern cities and urban sprawls clearly indicate the assumption of seemingly limitless energy that North Americans have made. Acres and acres of black pavement to park millions of automobiles. Glass skyscrapers that

DIAGRAM 3[2]


SOLAR ENERGY
Evaporation
Photosynthesis
Stored Potential Energy in Water 10^{15}W
Marine Plants 4×10^{14}W
Land Plants 5×10^{13}W
5×10^{22}J of stored fossil fuel
Food for Man 4×10^{11}W
Food for Animals 4×10^{12}W
Space Heating 2×10^{12}W
3×10^{10}W Hydro
Space Heating 3×10^{12}W
Nuclear Generating Stations 3×10^{9}W
10^{12}W used to produce 3×10^{11}W of electricity
Internal Combustion Engines 10^{13}W
Raw Materials for Plastics and Chemicals 10^{12}W
Electricity 3×10^{11}W
Light
Communication
Electrochemistry
Mechanical Power

need to be sooled during the summer and heated during the winter. Transportation can move food staples to central depots so that man can continue to expand his city. If little energy is available, then muscle energy might be the most common source of energy, and man might be compelled to seriously consider the efficient and wise usage of energy. The average Canadian consumes more than 300 times as much energy as the average Ethiopian. This fact alone is a good indicator of the lifestyle of these two people. The endless array of gadgets and energy-saving devices enjoyed in Western society are brought about by an enormous consumption of non-renewable fuel.

B. The Energies and Efficiencies in Agriculture

Agriculture provides a good case study how we have ignored energy in considering agricultural efficiency. Agriculture's green revolution which permits two crops a year, high-yielding soils, conversion of barren lands to fertile ones, has come about because of the expenditure of vast amounts of energy as can be seen in the following table and diagram. Whereas it should be properly called a "fuel" crisis, the term "energy" crisis is so widely used and accepted than they have become almost synonymous.)

ENERGY EFFICIENCY OF CORN PRODUCTION, 1970[3]

	Energy Intensive (U.S.)	Labour Intensive (Mexico)
Energy Investment per Hectare	$2.8 \times 10^{10} J$ (b)	$2.2 \times 10^{8} J$ (a)
Energy Return per Hectare	$7.5 \times 10^{10} J$	$2.9 \times 10^{10} J$
Efficiency: Return on Original Energy Investment	2.7	130

Notes:

(a) Assume a farmer consumes 2000 Calories/day

$$\frac{2000\ \text{Calories}}{\text{day}} \times \frac{1000\ \text{cal}}{1\ \text{Cal}} \times \frac{4.2\ \text{J}}{1\ \text{cal}} \times \frac{1\ \text{day}}{24\ \text{h}} \times \frac{1\ \text{hour}}{3600\ \text{S}} = 97\ \text{J / S}$$

$$= 97\ \text{Watts}$$

Assume the farmer works uninterrupted for 5 h/day for 100 days/year

Therefore, Energy input is

$$97\ \frac{\text{J}}{\text{S}} \times \frac{3600\text{S}}{1\ \text{h}} \times \frac{5\ \text{h}}{\text{day}} \times \frac{100\ \text{days}}{\text{year}} = 1.7 \times 10^{8}\text{J}$$

Add to this the input of mule or horse, and one obtains 2.2×10^{8}J/year/hectare for a Mexican farmer.

(b) The American farmer basically sits and drives his machinery, which consumes an energy of 2.8×10^{10}J/year/hectare. Thus the American farmer uses 127 times more energy per hectare $\frac{2.8 \times 10^{10}}{2.2 \times 10^{8}}$, but produces only 2.6 times as much food energy/hectare as the Mexican farmer. The efficiency factors are even more startling. The Mexican farmer achieves an efficiency of 130 compared to the 2.7 of the American farmer.

To produce the necessary food, fossil energy is used directly in the form of gasoline, diesel oil and electricity. Fossil energy is also used indirectly in the production of fertilizers, herbicides, and pesticides. Energy is used to bring the raw materials to the farm and to distribute the finished product. From the graph below, it is seen that the labout input is cut in half, the plant density within the hectare is doubled, and the total energy input/hectare is increased about threefold, as can be seen in the following graph which shows 30 units of energy input for 1970 and 11 for 1945.

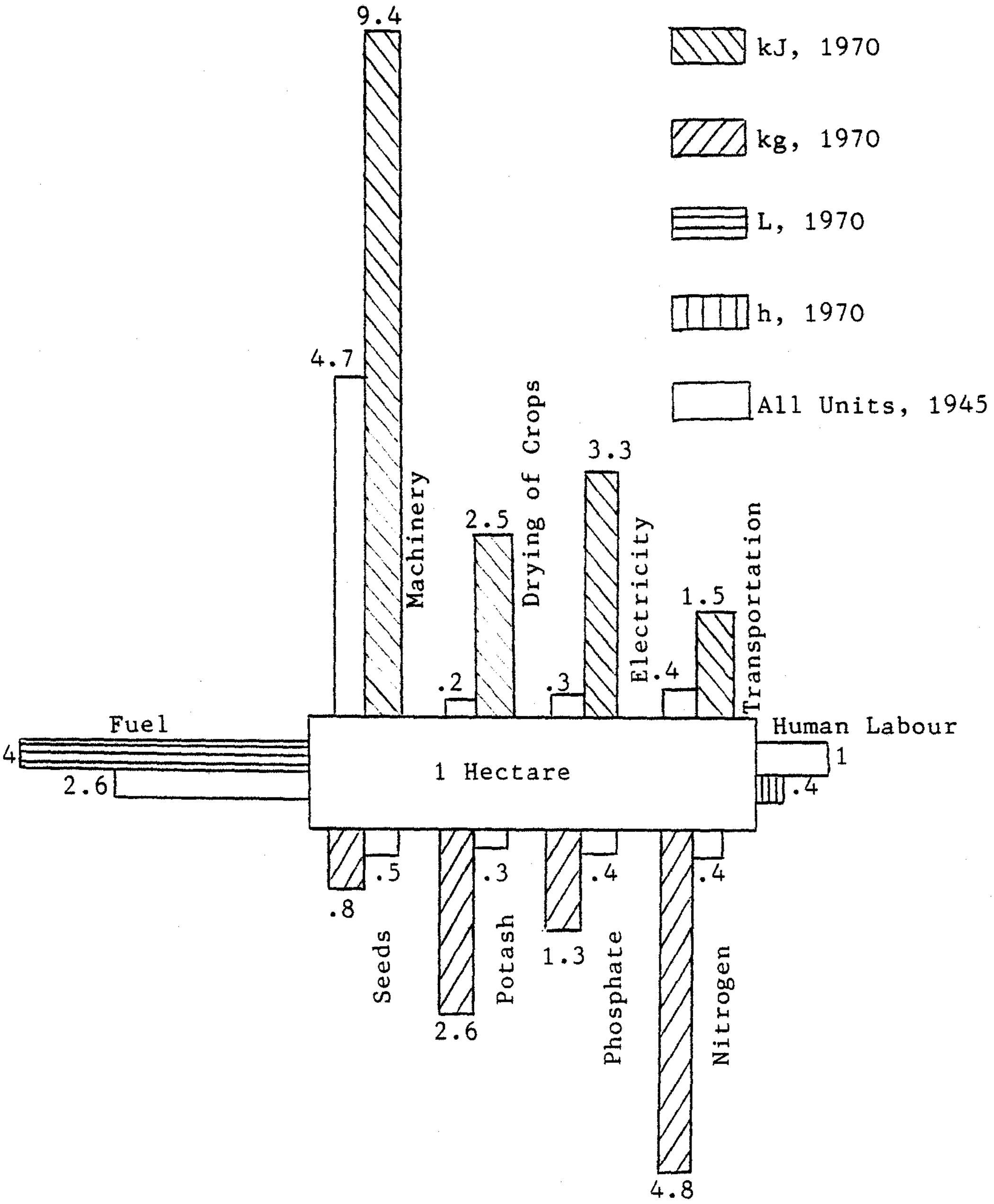
Although the energy return per hectare is 2.6 times more for the

U.S. than Mexico (from the previous table--7.5 x 10^{10}J vs. 2.9 x 10^{10}J), the energy input/hectare is 130 times greater (2.8 x 10^{10}J vs. 2.2 x 10^{8}J).

In the days of "almost free" energy, the American method is obviously much more productive than the Mexican. However, as energy becomes more and more expensive, the balance will tilt back toward more primitive but less greedy production practises.

TABLE 1[4]

Energy Inputs per Hectare, 1945 & 1970 for Western Food Production Practises



IV ENERGY AND SOCIETY

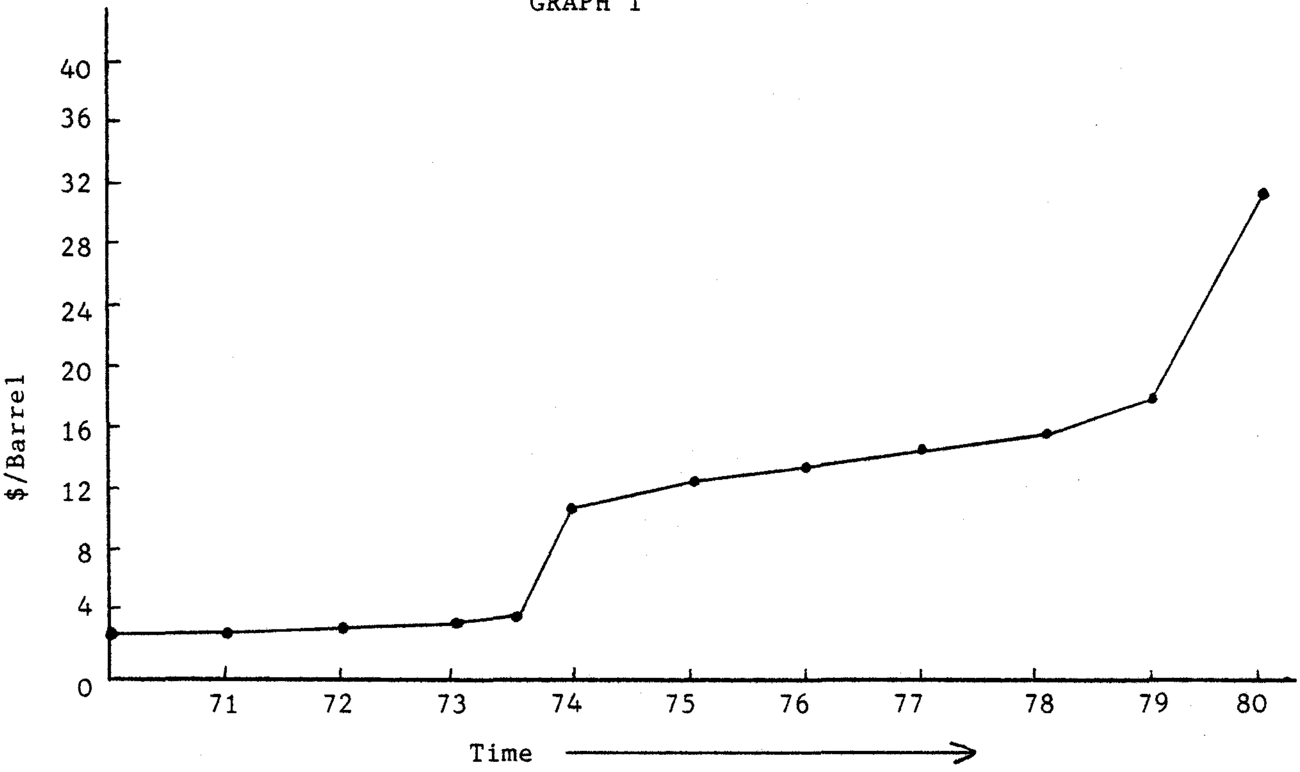
While the role of energy in the development of agricultural and industrial technology and in the advance of pure science has long been appreciated in the disciplines of science and engineering, the role of the energy sources available in determining the nature of a society has rather recently provided an intellectual foundation for such fields of study as sociology, history and economics. The Russian economist Kondratieff has developed a theory which explains the rise and fall of civilizations as cycles of societal activities based on economic activities which are in turn based on energy supplies. Thus the Netherlands was able to expand and flourish in the seventeenth century because it had learned how to utilize wind energy. Thus England was able to extend her Empire because coal was harnessed as the energy source, and the steam engine came into its own. Thus North America has been so successful because it learned how to tap the fossil fuels of gas and oil, which also produced the internal combustion engine.

But all these resources are now diminishing. Is North American civilization already in a state of decline? The answer will depend on how successful we are in bringing new energy resources into being.

The fossil fuel energy situation became critical in 1973 when OPEC placed an embargo on oil exports, and drastically increased prices, as shown below (see Graph 1).

This act accelerated world recession, and radically changed the opinions of governments and people about energy. So far we have been profligate in our use of energy. North America uses 35% of the world's oil supply but has only 5% of the world's population. But there is a detectable change. The sudden increase in costs have led to improvements

GRAPH 1[5]



in efficiency and demands for conservation so that the rate of increase in the demand for energy has dropped significantly. Moreover, significant sums of money are now being allocated to research in alternative sources of energy. Society is attempting to make decisions that will ensure an energy supply base for future generations and also for those peoples presently having little access to energy sources (the so-called "Third World"). In these decision-making processes we face a complex problem that has deep sociological, economic and technological overtones. We must weigh curtailment of energy-intensive activities against the achievement of desirable conservation practises. If we are to maintain our present standard of living, then drastic steps must be taken to reduce our demand on the fossil fuel reserves. The recently announced energy policy of the Federal government is designed to allow Canadian energy prices to rise to world levels at a rate which it is hoped that the public will accept. The policy will certainly create much tension in our society, since a lowering of energy use is in effect a reduction in the standard of living to which we have become accustomed.

V FACTORS AFFECTING ENERGY CONSUMPTION

A number of factors greatly affect the rate of consumption of energy. Three major ones have been chosen to be examined in some detail.

A. Average Rate of Energy Consumption per Person

1. Essential Energy Requirement

The amount of energy a person uses depends to a great extent on the lifestyle of that person. Primitive man had only the energy of the food he ate, which was about 2000 Calories or 97 Watts.

$$\frac{2 \times 10^6 \text{ cal}}{\text{day}} \times \frac{4.2 \text{ J}}{\text{cal}} \times \frac{1 \text{ day}}{24 \text{ h}} \times \frac{1 \text{ h}}{3600 \text{ S}} = 97 \frac{\text{J}}{\text{S}} \text{ or } 97 \text{ Watts}$$

Hence, in terms of energy requirements, man is equivalent to a 100 Watt light bulb. However, as man learned how to appropriate more and more energy to his use, his standard of living increased steadily and the quality of his life altered beyond recognition from that of his primeval forebearers.

The amount of energy available to man is the primary limiting factor as to what man can do and greatly influences what he will do.

2. Energy Conversions and Transitions in Lifestyles

Man has always converted energy from one form into another more desired form (see chart, p. 6). In the conversion process much energy is lost as waste heat. Whether it is from grass to beef, or wood to heat, muscle to transportation, coal to electricity--all conversions lose energy. The greater the number of steps involved in the conversion process the greater the amount of energy lost. There is no conversion without a loss of energy to the heat form. Unfortunately, as lifestyles rise, so do the number of conversions.

From an historical perspective, we can obtain some data of how the amount of energy consumed changes drastically as the lifestyles change. Primitive man without the use of fire had only the energy of the food he ate. Hunting man had more food and also burned wood for heat and cooking. Primitive agricultural man was growing crops and had gained animal energy. Advanced agricultural man had some coal for heating, some water and wind power and animal transport. Industrial man had the steam engine. Technological man has added oil, gas and water power to his energy budget, and uses electricity to transport this energy efficiently and rapidly. The table (see page 18) presents a picture of the amounts of the per capita energy available to man in different styles of society, and how he distributed that energy to suit his needs.

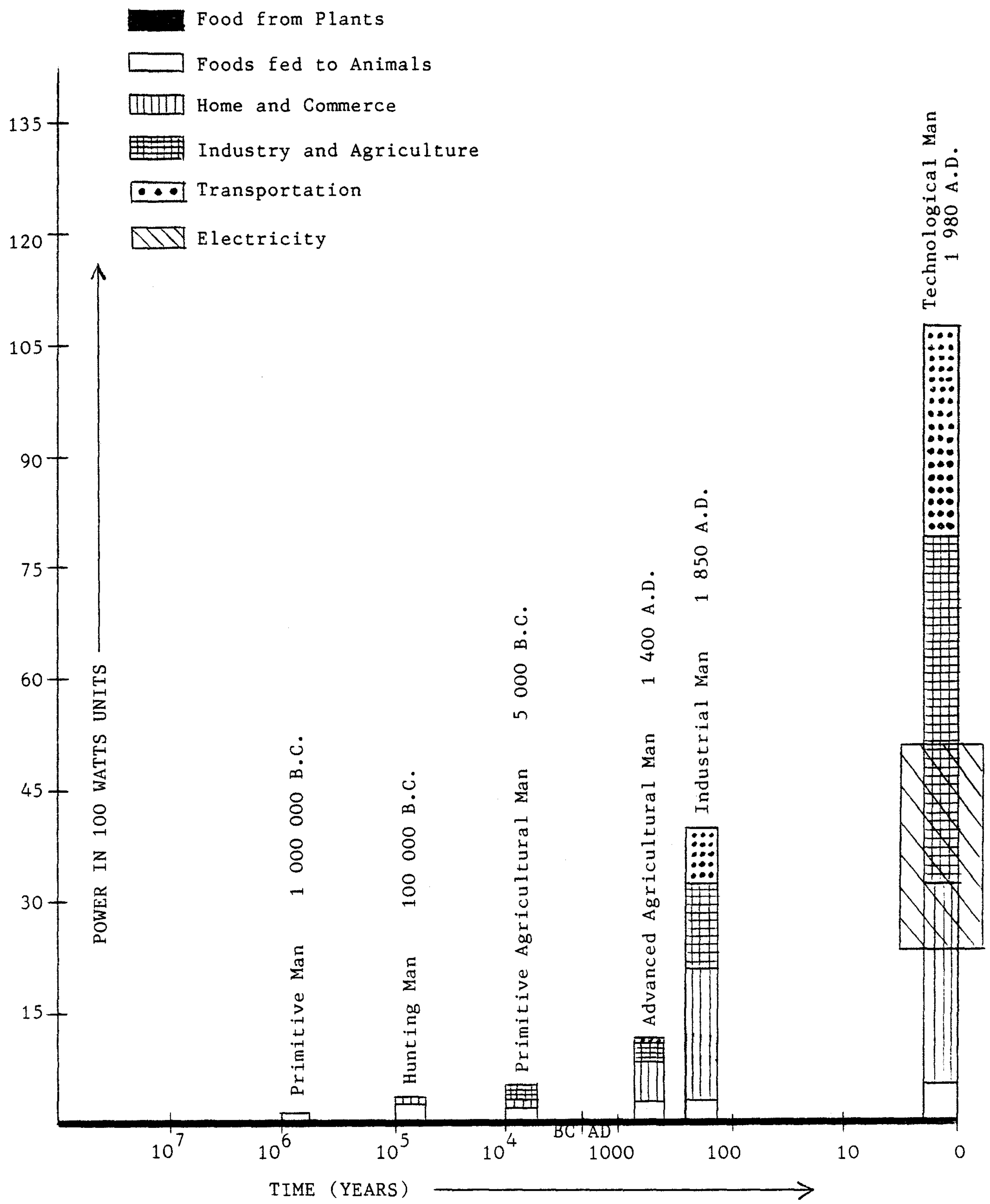
A more dramatic pictorial representation of the same information is shown in the graph (see page 19). The explosion in energy use over the last 300 years is strictly due to the exploitation of fossil fuels. As can be seen from the graph, the function that energy serves as civilization progresses changes radically from one of sheer necessity to one of sheer luxury. Also, electricity becomes very important as a means of energy delivery for technological man.

Predictions from the graph are not warranted, but certainly trends can be observed. The increase in power in the last 200 years is awesome. If it were to continue, we could readily see how quickly the power increases relative to time. The graph is almost parallel to the Power axis when technological man comes on the scene. Note that the "base" line

TABLE 2[6]

Species	Time	Energy Consumption Mega in Joules Per Day	Power in Watts	Light Bulb (100 W) Equivalence (approximate)	Energy Distribution in Mega Joules/Day
Primitive Man	1 000 000 B.C.	10	116	1	10 for food
Hunting Man	100 000 B.C.	25	289	2.9 - 3	15 food, 10 for home
Primitive Agricultural Man	5 000 B.C.	60	694	7	20 food, 20 home, 20 agriculture
Advanced Agricultural Man	1 500 A.D.	130	1484	15	30 food, 60 home, 35 industry & agriculture, 5 transportation
Industrial Man	1 875 A.D.	385	4395	44	35 food, 160 home, 120 industry & agriculture, 70 transportation
Technological Man	1 970 A.D.	1150	13128	131	50 food, 330 home, 455 industry & agriculture, 315 transportation

GRAPH 2: Graph of Power vs. Time of Mankind[7]



remains constant--to stay alive, man doesn't need any more energy than his ancient predecessors. The trend indicates a doubling period of approximately 35-40 years.

3. Historic and Present Sources of Energy

It is also useful to determine how the source of energy or fuel changed over the past 200 years. By 1900 coal supplied 70% of the energy, and in 1950, oil and gas were supplying 60% of the energy.

TABLE 3[8]

FUEL TYPES FOR ENERGY+ OF U.S.A.

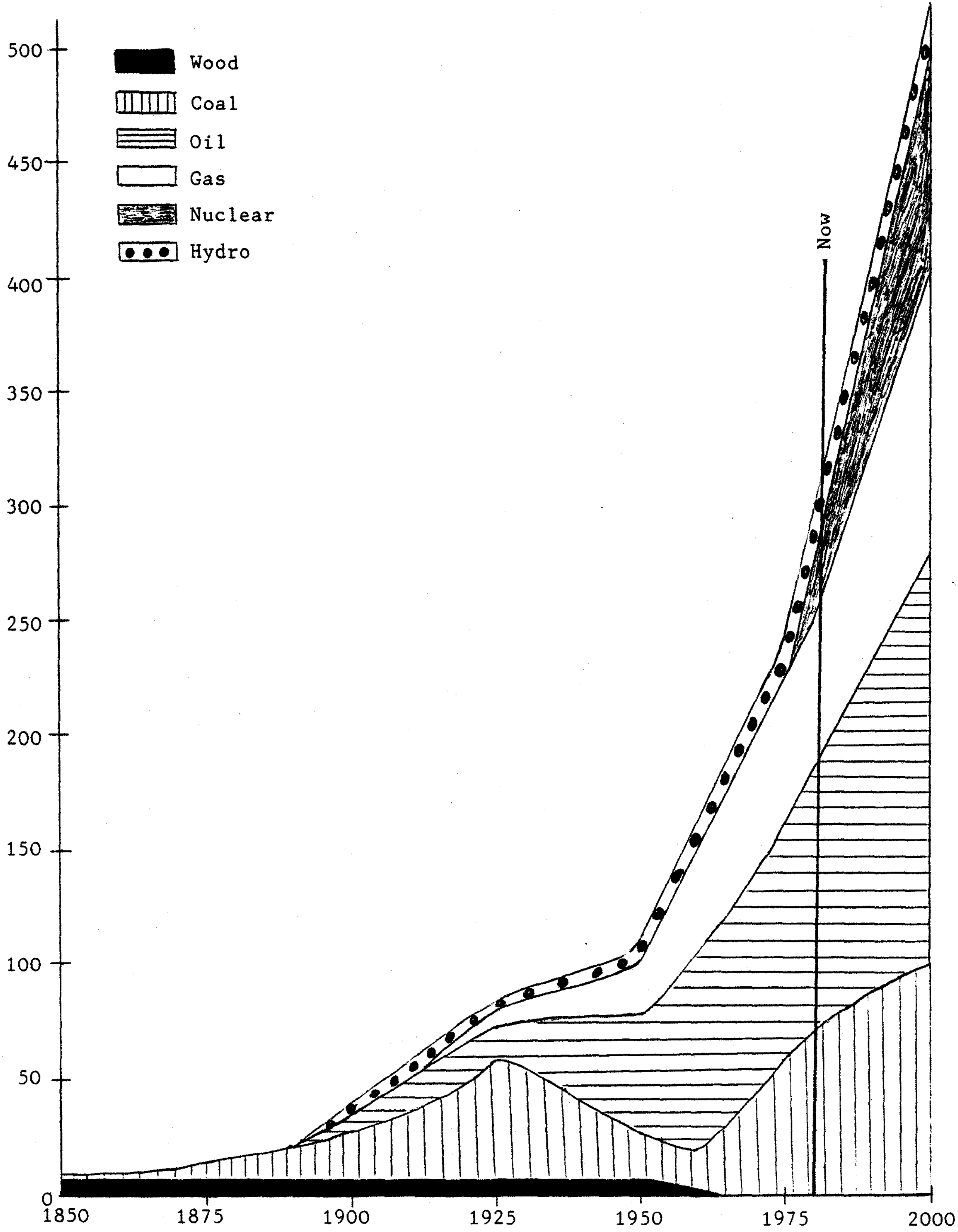
Year	Wood	Hydro	Coal	Oil	Gas	Nuclear
1850	6×10^{10}	0	7×10^{9}	0	0	0
1875	7×10^{10}	0	6×10^{10}	0	0	0
1900	6×10^{10}	1×10^{10}	24×10^{10}	3×10^{10}	0	0
1925	5×10^{10}	3×10^{10}	48×10^{10}	15×10^{10}	3×10^{10}	0
1950	3×10^{10}	3×10^{10}	24×10^{10}	42×10^{10}	24×10^{10}	0
1975	0	7×10^{10}	54×10^{10}	108×10^{10}	90×10^{10}	3×10^{10}
2000	0	8×10^{10}*	96×10^{10}*	180×10^{10}*	135×10^{10}*	90×10^{10}*

* Predicted Values

\+ Adopted from Scientific American, September 1971, p. 39.

This information can be plotted in various manners, but the one done shows how each fuel type changes with respect to time, and also shows how the total amount increases relative to time. The North American consumption has been multiplied some 30 times since the time wood supplied 95% of the energy.

GRAPH 3: Power and Sources of Fuel vs. Time of U.S.[9]



Note that from 1900 to 1975 the North American consumption rose from about 35 Watts to about 270 Watts. This represents a doubling factor of 25 years.

1900 = 35 Watts
1925 = 70 Watts
1950 = 140 Watts
1975 = 280 Watts

From these figures it is readily seen that in exponential growth the amount consumed per time period is equal to the total amount consumed previous to that time period. The percentage of world energy supplied by main fuels from 1900 - 1975 is as follows:[10]

FUEL	1900	1920	1940	1960	1965	1975
Coal	94.2	96.7	74.6	52.1	43.2	31
Oil	3.8	9.5	17.9	31.2	36.7	47
Gas	1.5	1.5	4.6	14.6	17.8	20
Hydroelectric & Nuclear	0.5	2.0	2.9	2.1	2.2	2

The total amount of coal consumed has increased world wide.[11]

Year Year	Solid Fuel	Oil	Gas	Hydro/ Nuclear	Total	per capita kg. of coal equivalent/year
		(tonnes of coal equivalent x 10^6)				
1929	1367	255	76	14	1713	867
1937	1361	328	115	22	1826	900
1950	1569	636	273	41	2519	1054
1955	1816	948	397	59	3211	1200
1960	2204	1323	620	86	4233	1403
1965	2250	1919	926	118	5213	1588
1970	2388	2855	1421	157	6821	1893
1972	2407	3219	1603	180	7409	1984
1975	2700	3604	1701	185	8190	2074

The figures are approximate, but it is seen from the last two columns in the above data table that the energy consumption world-wide is running at a doubling factor of 25 years. This represents a net growth of less than 3% per year, but is very significant. In the next graph the last column is plotted against time, and it is alarming how quickly the consumption of energy is increasing. This increase can be attributed to a rise in the standard of living. Even though North America might have reached a plateau in the standard of living, and might even experience a negative growth for some years to come, there are many more peoples that are fighting desperately to improve their lot in life. Surely this wish to improve living conditions cannot be denied. World-wide energy consumption rates will increase.

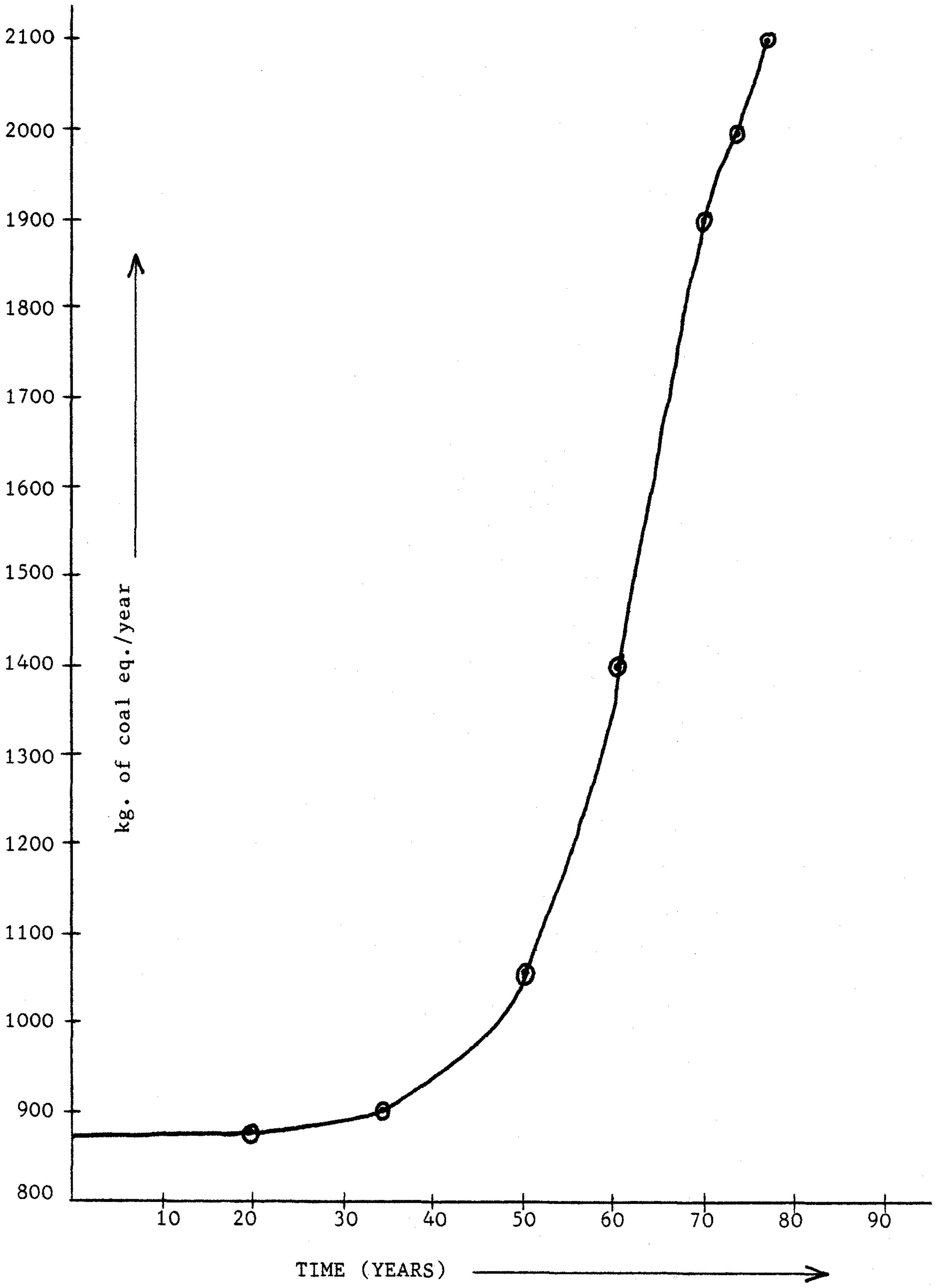
4. Energy Consumption Projections

(a) Energy Consumption vs. G.N.P.

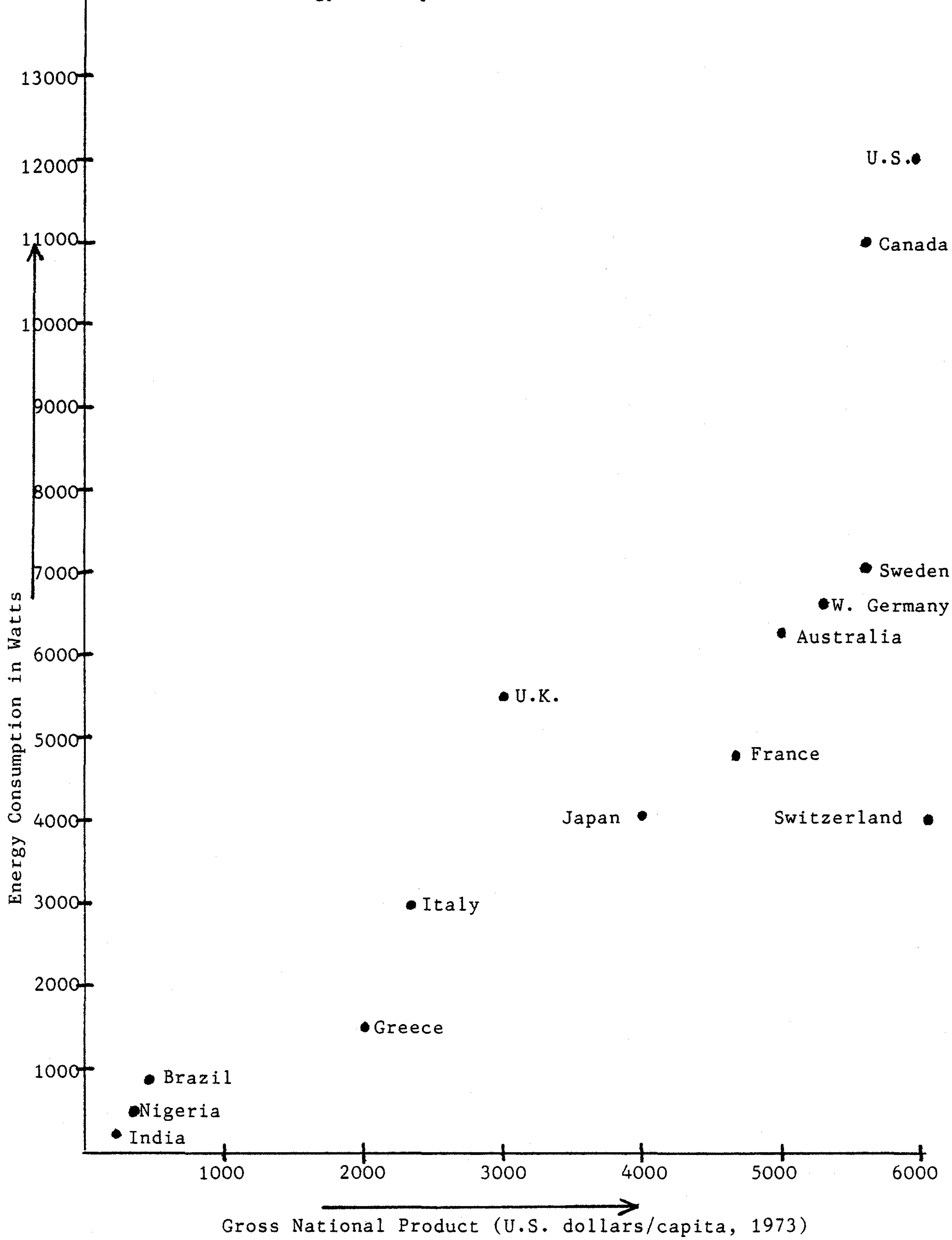
To determine to some extent how much energy consumption will rise because people desire to achieve a higher standard of living, one can graph the G.N.P. vs. Energy and note that indeed the U.S. and Canada consume more energy proportionately than any other country (see page 25). In some of the less developed countries the per capita energy consumption is not substantially higher than it was a million years ago. The great disparity between the per capita energy consumption and Gross National Product can be seen readily from the following graph.

During the last two decades, the rate of growth of energy consumption in the less developed countries has been faster than in the industrialized nations. However, the great increase in energy prices has hurt these countries very much since they have little cash reserve to buy energy. The availability and cost of energy will play a crucial role in

GRAPH 4: Graph of Coal (World) Consumption vs. Time



GRAPH 5: Energy Consumption vs. GNP in Selected Countries[12]



determining economic activity in both the developing and the industrialized countries.

Suppose that the energy consumption remains constant in the industrialized countries (or nearly so) and the less developed countries attempt to attain the same level. What would happen to the world's energy demand?

The world today consumes about 8×10^{12}W of power, which divided by a world population of about 4×10^{9} people averages out to about 2×10^{3}Watts. In the following graph (see page 27) note that about 70% of the world's population consumes less than that, and a considerable number of people exist on 200 Watts or less! Twenty-two percent consume 2 - 7 kW, and six percent more than 7 kW. North Americans consume 12 kW.

(b) A Proposed Scenario for Future Energy Consumption

In order to come up with some type of estimate or "guesstimate", it is feasible to divide the world first into regions that relate to energy demand (see page 28).

The division into seven regions is somewhat arbitrary but it does give us a "handle" on determining to some extent what the energy requirements for the world in say the next 50 years might be. In order to do this, it is wise to determine to what extent each region might expand in the future. Two scenarios can be developed: one of low development growth with regard to energy growth and a heavy emphasis on conservation, and one on a modest growth.

GRAPH 6: Graph of Per Capita Energy Consumption vs. Countries[13]

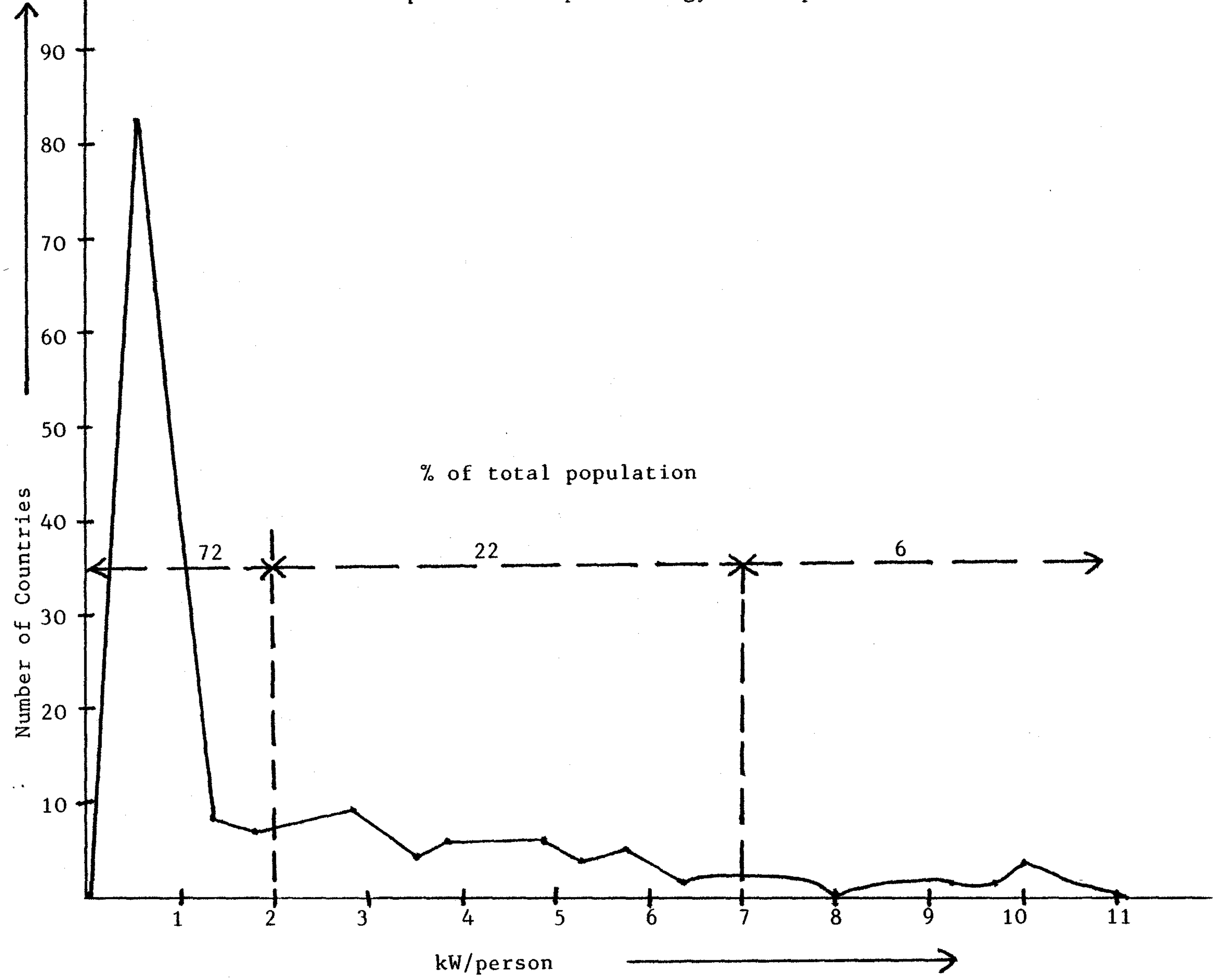
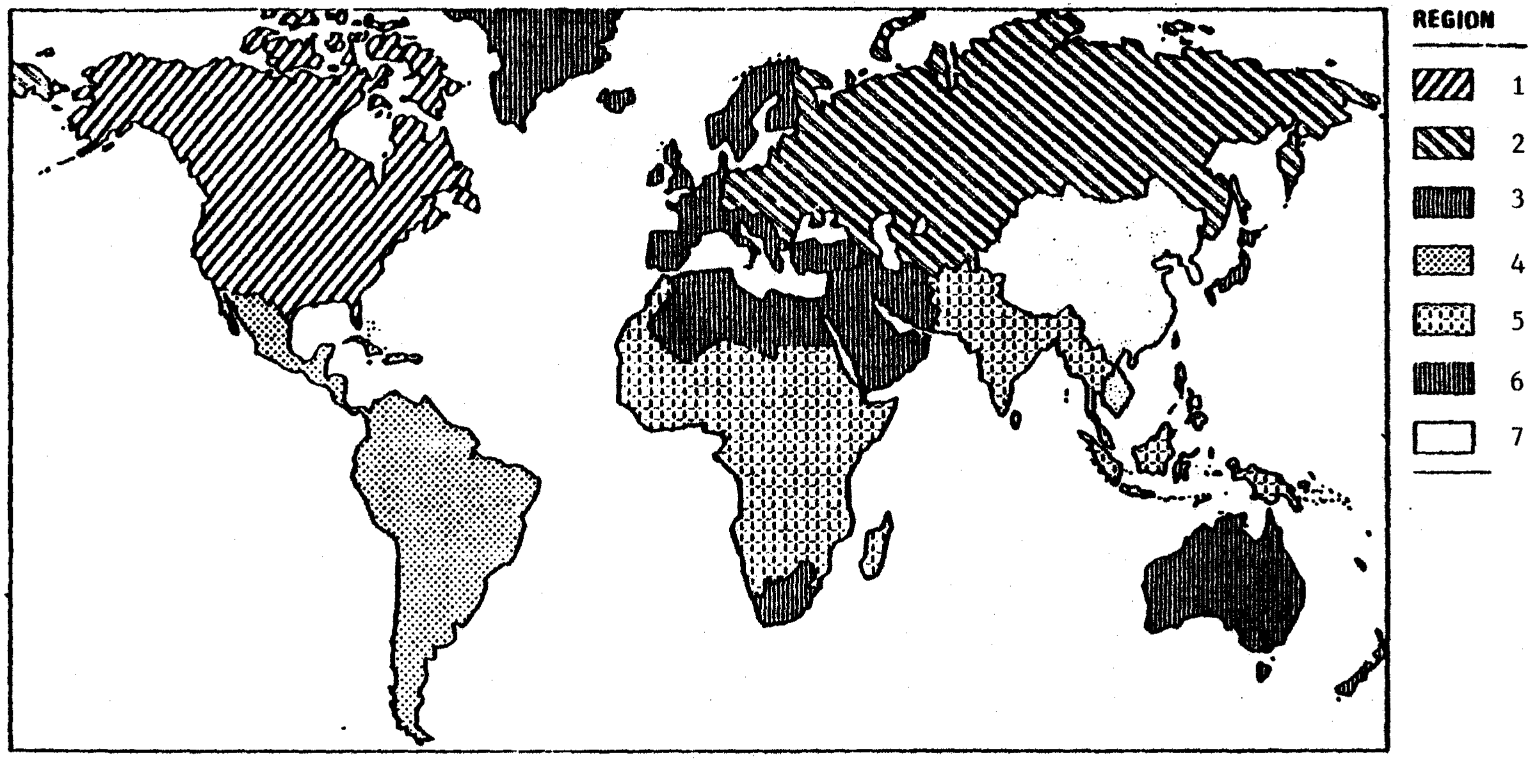


FIGURE 1: Seven World Regions[14]



1. (NA) North America
2. (SU/EE) The Soviet Union and E. Europe
3. (WE/JANZ) W. Europe, Japan, Australia, New Zealand, S. Africa, and Israel
4. (LA) Latin America
5. (Af/SEA) Africa (except Northern Africa and S. Africa), South and Southeast Asia
6. (ME/NAf) Middle East and Northern Africa
7. (C/CPA) China and Centrally Planned Asian Economies

Region	GDP per capita $ 1975	Growth Rate of Per Capita (% yr)[15]			
		High Scenario		Low Scenario	
		1975 - 2000	2000 - 2030	1975 - 2000	2000 - 2030
1	7046	2.9	1.8	1.7	0.7
2	3416	3.6	3.2	3.1	1.9
3	4259	3.0	1.8	1.7	0.9
4	1066	3.0	2.4	1.6	1.9
5	239	2.8	2.4	1.7	1.4
6	1429	3.8	2.8	2.4	1.2
7	352	2.8	2.4	1.6	1.4

The low scenarios for regions 1 and 3 indicate the trend towards zero-growth, and region 2, while somewhat higher, tends to follow the same trend. Region 6 has and will continue to have the highest growth rate. Certainly this has been borne out, e.g. Canada had a net G.N.P. growth rate of 0.1%.

One factor ought to be introduced here. Even though a decrease in energy demand is essential, there are some processes that cannot operate effectively without the so-called liquid fuels. Transportation, feed-stocks, the petro-chemical industry, etc. require oil and gas. The demand that these processes place on these fuels will increase, as shown in the table below:[16]

PERCENT OF LIQUID FUEL DEMAND USED FOR TRANSPORTATION AND FEEDSTOCKS			
REGION	1975	HIGH 2030	LOW 2030
1	74	94	91
2	65	100	100
3	52	86	76
4	69	90	89
5	58	91	88
6	74	94	91

This would seem to indicate that the production of electricity must be drastically increased, and should approach perhaps 20% of final energy. The energy per capita in kW might be as follows:

Regions	1975	High 2030	Low 2030
1 & 3	6.2	12.2	8.2
4 & 5	0.4	1.9	1.1
World	2.1	4.5	2.8

The low estimate seems reasonable; even so, it yields a world-wide demand of 2.8 kW per person, as compared to a present demand of 2.1, which is a minimum 35% increase.

The global primary energy demand can also be projected on the basis of a high and low scenario, as follows. Of course, there is much conjecture and plain guessing here, but trends can be useful.

GLOBAL PRIMARY ENERGY DEMAND PROJECTIONS[17]

REGIONS	1975 (TW)*	HIGH 2030 (TW)*	LOW 2030 (TW)*
1 & 2 & 3	6.8 TW	20.5	13.9
4 & 5 & 6 & 7	1.5 TW	15.2	8.5
World	8.2 TW	35.7	22.4

* 1TW = 10^{12} Watts

Suppose a lower projection is required--say a global consumption of 16×10^{12}W by the year 2030. This is only a doubling of energy requirements in the next 50 years. If this is to take place, then the high demand countries must experience a negative growth, which could well take place. A 16×10^{12}W demand is equivalent to 2 kW/person. Redistribution might take place as follows:

Regions	Base Year 1975	2000	2030
1	11.27	9.1	8.0
2	5.10	7.2	6.2
3	4.03	3.6	3.2
4	1.06	1.8	2.8
5	0.23	0.5	0.7
6	0.96	2.2	3.6
7	0.51	1.0	1.2
World	2.1	2.0	2.0

Whether a negative growth can be effecntively carried out is a matter that is hotly debated in various circles. Conservation is basically striving for a negative growth (use less). Politically, a negative growth might not be feasible.

CONCLUSION:

Given the present demand (world-wide) on energy, it seems highly likely that a doubling factor of 35 years (approximately a growth rate of 2% world-wide) is almost unavoidable. This is largely due to the demand that the less developed countries will make--and rightly so--upon the global energy reserves.

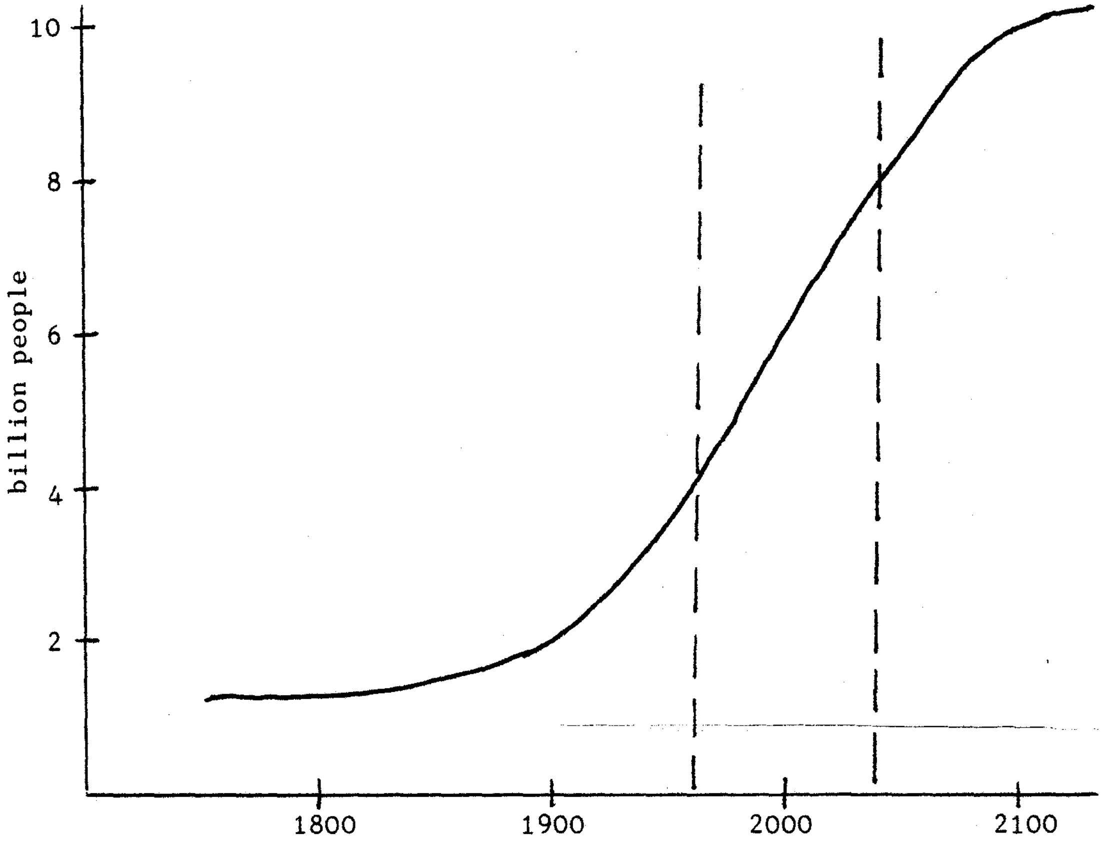
B. World Population

Whatever energy demands may be exercised in the next fifty years (after 50 years other sources of energy must be available), there is one major over-riding factor--population growth--that has an extremely important effect on the outcome of energy demand and resources.

The standards of living could remain constant--even become negative--but as long as population increases, the energy used must increase.

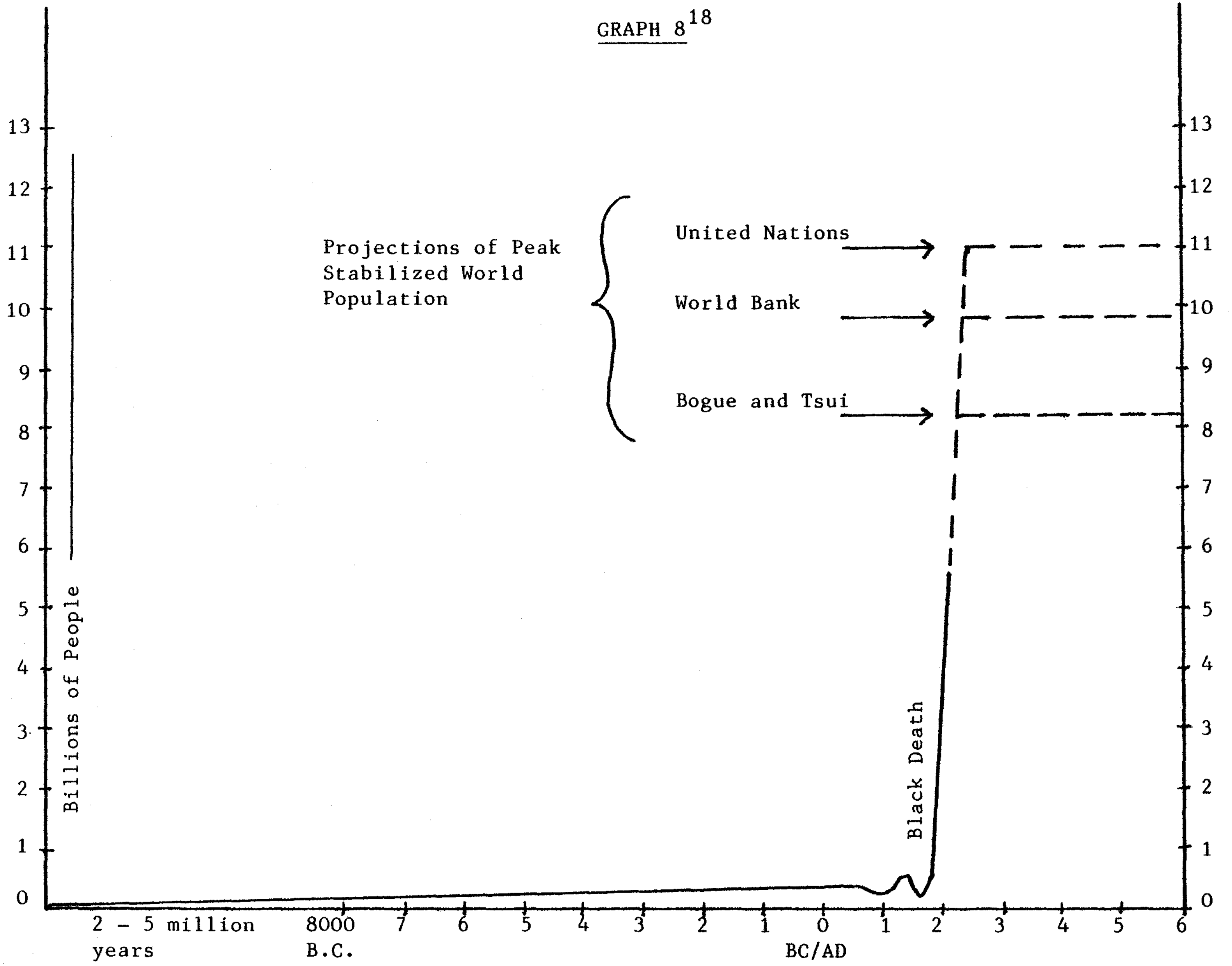
The rate of population growth has been discussed in great detail in the last few years. A graph of the form sketched below has occurred frequently:

GRAPH 7



Today there are about 4.5 billion on earth. What happens in the next 25 years will very much influence the energy demand. The "population control" is still with us. The statement "take care of the people and population will take care of itself" or "development is the best contraceptive" might in fact be wishful thinking. As the less developed countries attempt to achieve some modest level of development, will that necessarily correspond to a decrease in the fertility rate, and more importantly, will it occur soon enough?

In the following graph, it is demonstrated rather starkly how population has increased dramatically. It took a few million years to reach a population of about half a billion in 1650; by 1930 it was two



GRAPH 8[18]

Projections of Peak Stabilized World Population
United Nations
World Bank
Bogue and Tsui
Black Death
Billions of People
0
1
2
3
4
5
6
7
8
9
10
11
12
13
2 - 5 million years
8000 B.C.
7
6
5
4
3
2
1
0
BC/AD
1
2
3
4
5
6

billion; it doubled to four billion in 1975, and it is projected to nearly six billion in the year 2000. There are three projections that state a stable population of eight, ten, or eleven billion people by 2050, 2090 or 2125 A.D.

The explosive build-up of world population is putting tremendous pressure on earth's resources and social fabric. These pressures are felt most acutely in the less developed countries.

As we can see in the following map and data, most of the growth is taking place in the less developed countries: Latin America, Africa, and Asia (minus Japan). These regions are growing at an annual rate of about 2% which is a doubling period of 35 years. The developed regions by contrast are growing at a rate of 0.7%/year, a doubling period of approximately 100 years.

The World Fertility Survey surveys 60 countries--41 developing and 19 developed--and has already detected some flaws in some basic demographic beliefs. The so-called demographic transition period identifies four basic stages in the evolution of a country's population.

First, prior to industrialization, the birth rate is high, but so is the death rate; the population grows slowly. Industrialization and the improved living conditions, increase the life span of many children, and the population explodes. This is the second stage. Stage three is the transition stage where families require fewer children, and insist on more personal enjoyment, and the population explosion slows down. Stage four occurs when the fertility rate is equivalent to the required replacement rate. Note that the dropping of the fertility rate is caused by an increased standard in living. This leads to the contraceptive view of development.

WORLD:

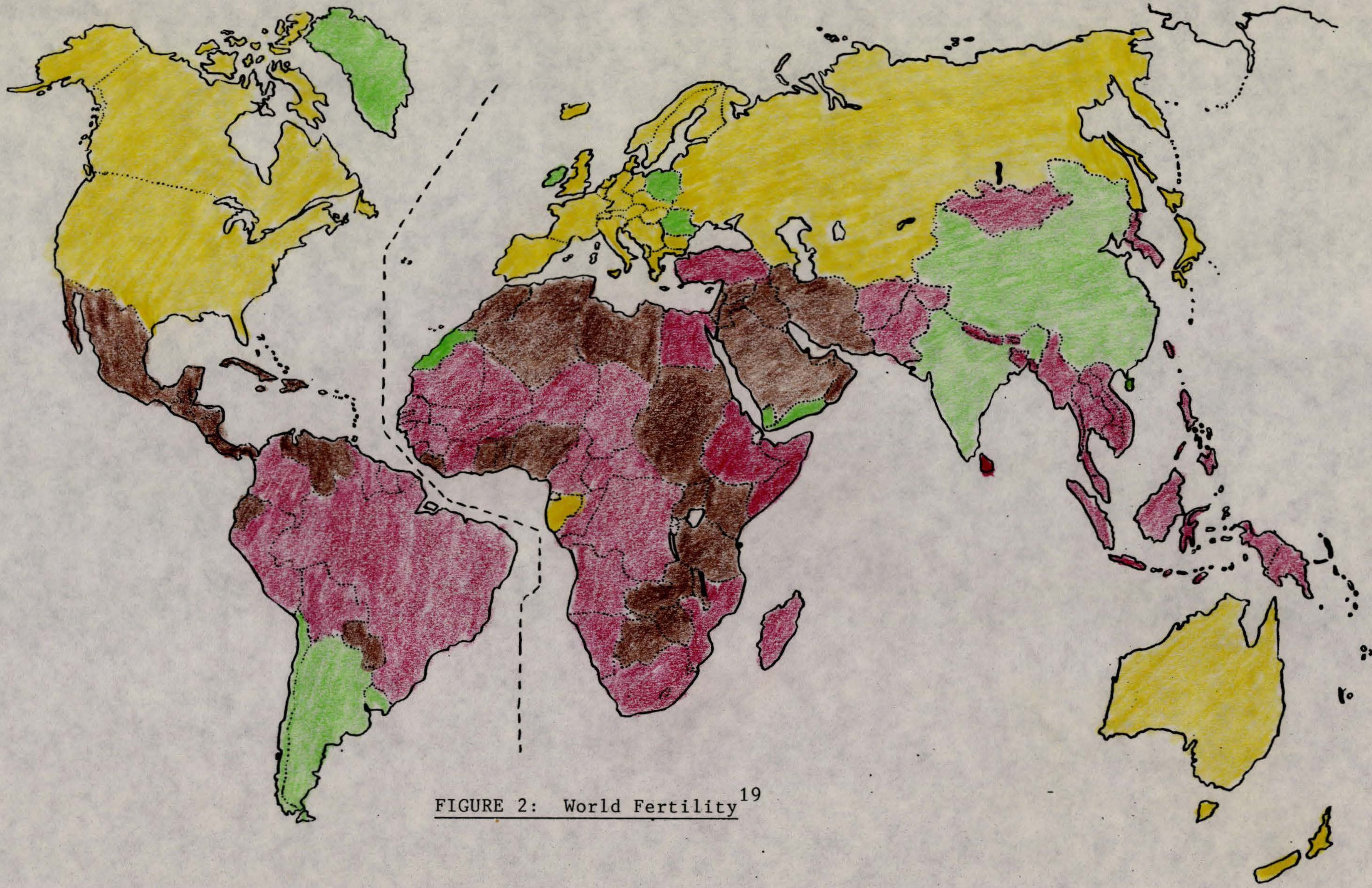


FIGURE 2: World Fertility[19]

(Countries with the highest fertility are shown in red; lowest fertility in yellow.)

NOTE: In the previous map, the annual rate of population increase is given by the following code:

BROWN = 3 - 3.9% RED = 2 - 2.9%

GREEN = 1 - 1.9% YELLOW = 0 - 0.9%

The number of years required to double the population of some of the countries is listed in the following table:

Country	Number of Years for Population to Double
Canada	88
U.S.A.	99
Caribbean	36
Brazil	25
U.K.	1155
France	198
Sweden	1386
Egypt	26
Kenya	18
Jordan	21
U.S.S.R.	82
India	36
China	58
Indonesia	34
Australia	86

The results from the World Fertility Survey (1979) indicate that the transition period is not a bad generalization, but it does have some weaknesses and faults. It could be that the fertility rate is more closely related to cultural standards, religion, etc. There is one bright hope--from all surveys, the message is clear: Women want fewer children, whatever their socio-economic status in society. Some countries have exceedingly high birth rates. In Kenya, for example, the average woman has just over 8 children, which gives Kenya a doubling period of 18 years--the greatest of all countries.

The latest report from the United States Census Bureau adds an optimistic note by stating that the global rate of population has decreased from 2.1% in 1965-70 to 1.7% in 1975-79, indicating that the doubling period has increased from 33 years to 41 years. The most recent measures in China to curb population also adds to an optimistic view that population can be controlled and reach a controllable plateau, whether that be 8, 10, or 12 billion. The world can provide for 8 billion, but 12 billion is perhaps beyond earth's resources. Fertility must be reduced. Soon. The one billion or so young people of today must be shown the drastic effects of exponential growth in human population. Canada's population growth occurred as follows:[20]

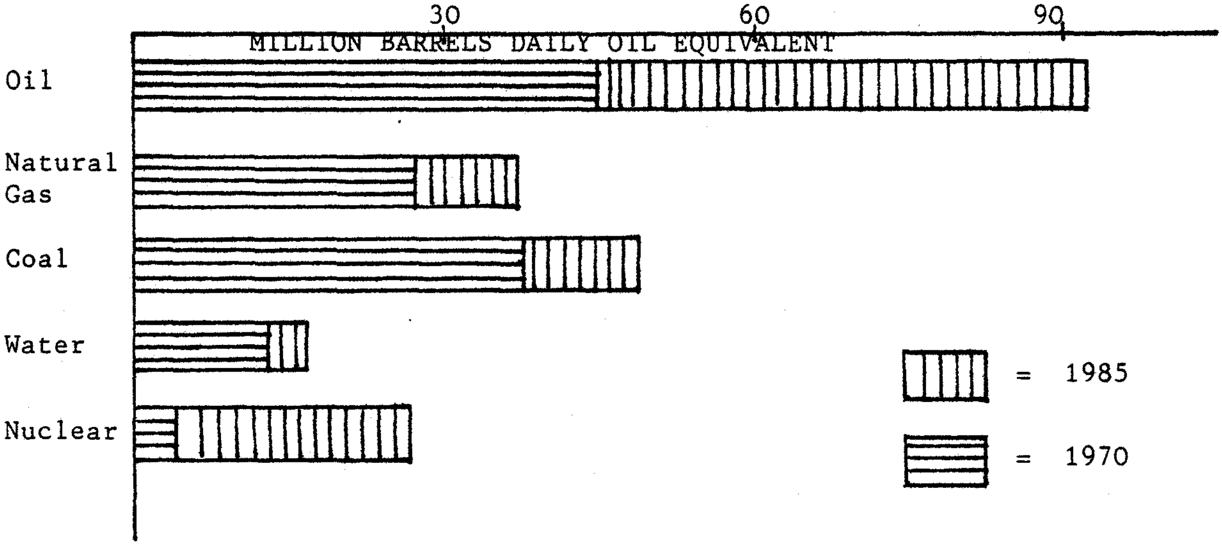
1851	2.4×10^6	1901	5.4×10^6	1951	14.0×10^6
1861	3.2×10^6	1911	7.2×10^6	1961	18.2×10^6
1871	3.7×10^6	1921	8.8×10^6	1971	21.6×10^6
1881	4.3×10^6	1931	10.4×10^6	1981	23.0×10^6
1891	4.8×10^6	1941	11.5×10^6		

So far we have discussed two basic factors that directly affect the rate of energy consumption: (i) Lifestyle influencing the rate of energy use and (ii) the number of people. Can any conclusions be drawn? Perhaps only one can be drawn: If the less developed countries wish to achieve a modicum of existence at a standard of living that moves beyond the perpetual poverty and starvation level, then the North Americans might well have to decrease their demand on energy. If we look at our chart on page 30, we notice that energy demands increase considerably in regions 1, 2, and 3. Is this necessary? The table on the bottom of page 30 gives a more realistic picture. In 1975 the world-wide energy consumption was 2.0 kW/person. If this is kept constant, then the developed countries must sharply decrease their rate of consumption. For example: in 1977 Canada consumed a total of 7×10^{18}J (10 kW/capita) with a population of 2.3×10^{7}. If this were world-wide, then the total world consumption in 1977 would have been $\frac{4.6 \times 10^{2}}{2.3 \times 10^{7}} \times 10^{18} \times 7 = 14 \times 10^{20}$J whereas the actual consumption was 2×10^{20}J. Again, the Canadian rate is about seven times the world rate. But such a reduction in energy consumption is perhaps highly unrealistic. Even if the total global consumption remains constant at 2 kW, the increase in population will still increase the total amount of energy consumed per annum. If the population is going to double in the next 50 years, then the annual energy consumed will also double. Population growth is still a major concern. It will not be stabilized until about 2030, since by 1990 there will be a billion people between the ages 15 and 29 years. It is this group that will decide whether to have a family, and if so, how many children to have. To determine to some degree the effect that this increase in energy consumption will have, we must look at world resources, and determine what will happen to these resources.

C. The Energy Supply

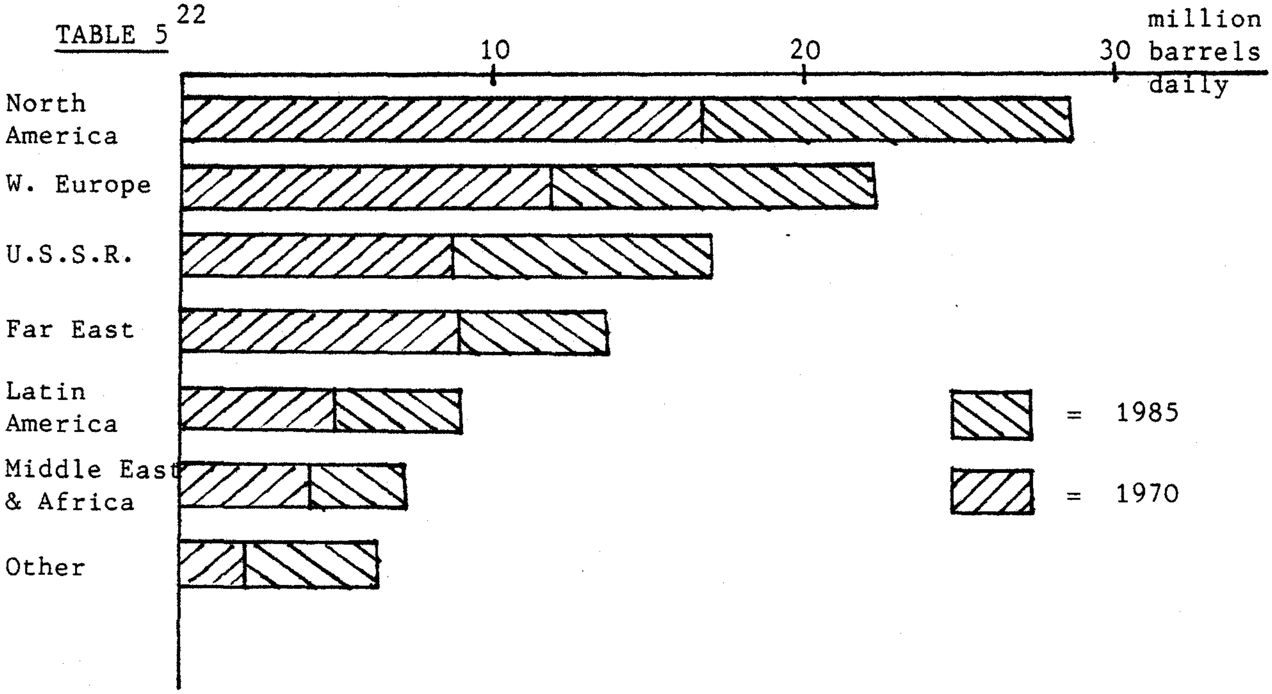
The basic sources of energy are oil, natural gas, coal, water, and nuclear. The scale of these resources and where they are used is presented in the table below.

TABLE 4: World-Wide Energy Use by Source[21]



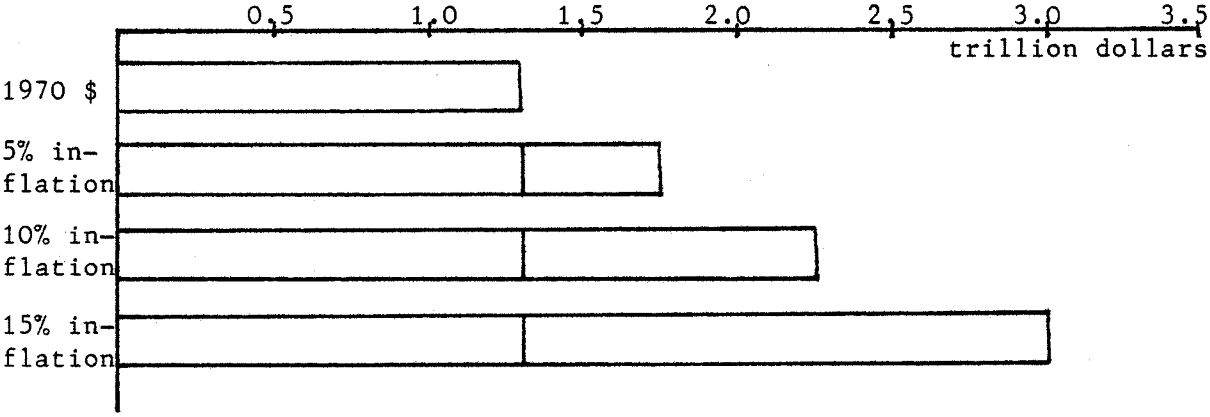
Oil is by far the largest source of energy, and the world-wide demand for it continues to grow.

TABLE 5[22]



North America is still the largest market, but by 1985 it will be 25% of the total demand, and will continue to decrease as other less developed countries increase their demands. From 1955-1970, there was a 7.5% growth factor and 153×10^9 barrels of oil were consumed. From 1970-1985, there is an approximate 4% growth, but a total of 375×10^9 barrels of oil consumed.[23] Even if there is no growth, then it would still require 310 billion barrels of oil.

TABLE 6: Petroleum and Industry's Financial Needs[24]



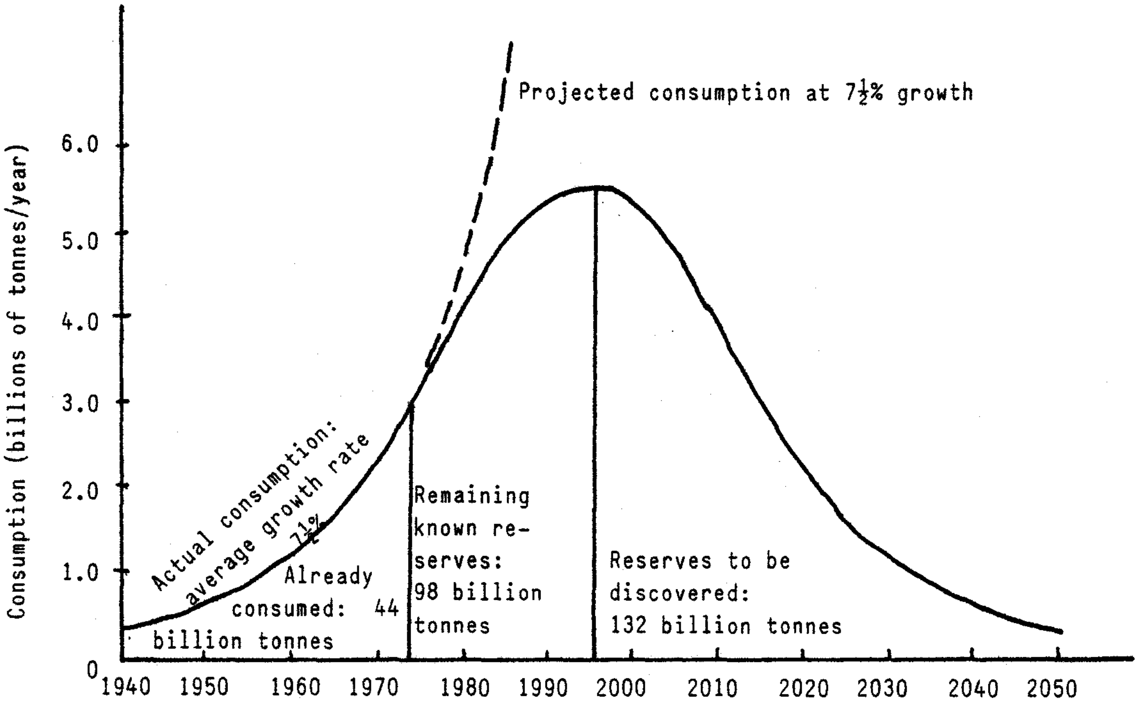
Inflation will have an enormous impact on the money sources. If these monies (from the above graph) are required, then the consumer will ultimately pay. For example: if a litre of gasoline costs 30 cents today, then at a 10% annual inflation it would cost 60 cents in 7 years. Now add to this all the other factors, such as well-head increases in oil, etc., and the sixty cents might well be here in two or three years. Cost of extracting oil is important if we are to determine—to some extent—how long the oil supply will last.

The total reserves (oil) in the world has been estimated by Hubbert to be 2×10^{12} barrels[25] [1 barrel = 5.9×10^9 J] and most scientists feel that his estimate is credible. However, some are much more optimistic. For example, Odell suggests that the resources are a factor of two greater--4 x 10^{12} barrels.[26]

H. William Menard, in the January 1981 Scientific American, uses computer simulation based on historical methods of drilling for discovery of oil, and concludes that in the United States all major oil fields have been discovered. There are, no doubt, many small fields that are still untapped, but economically it would not be feasible to tap them. Menard estimates the U.S. reserves at 30 x 10^9 barrels, and the North Slope of Alaska may add another 10-15 x 10^9 barrels. At an annual consumption of about 6 x 10^9 barrels, the supply would be depleted in about ten years. The United States imports about 50% of its oil, which extends this period.

The theoretical depletion curve for world oil reserves is shown below, and various authors (Hubbert, Foley, Menard, Häfele) are in fair agreement with this projection.

GRAPH 9: Theoretical depletion curve for world oil reserves of 274 billion tonnes[27]



Häfele uses Hubbert's estimates (or close to them) and has made a summary of the ultimate recoverable resources:[28]

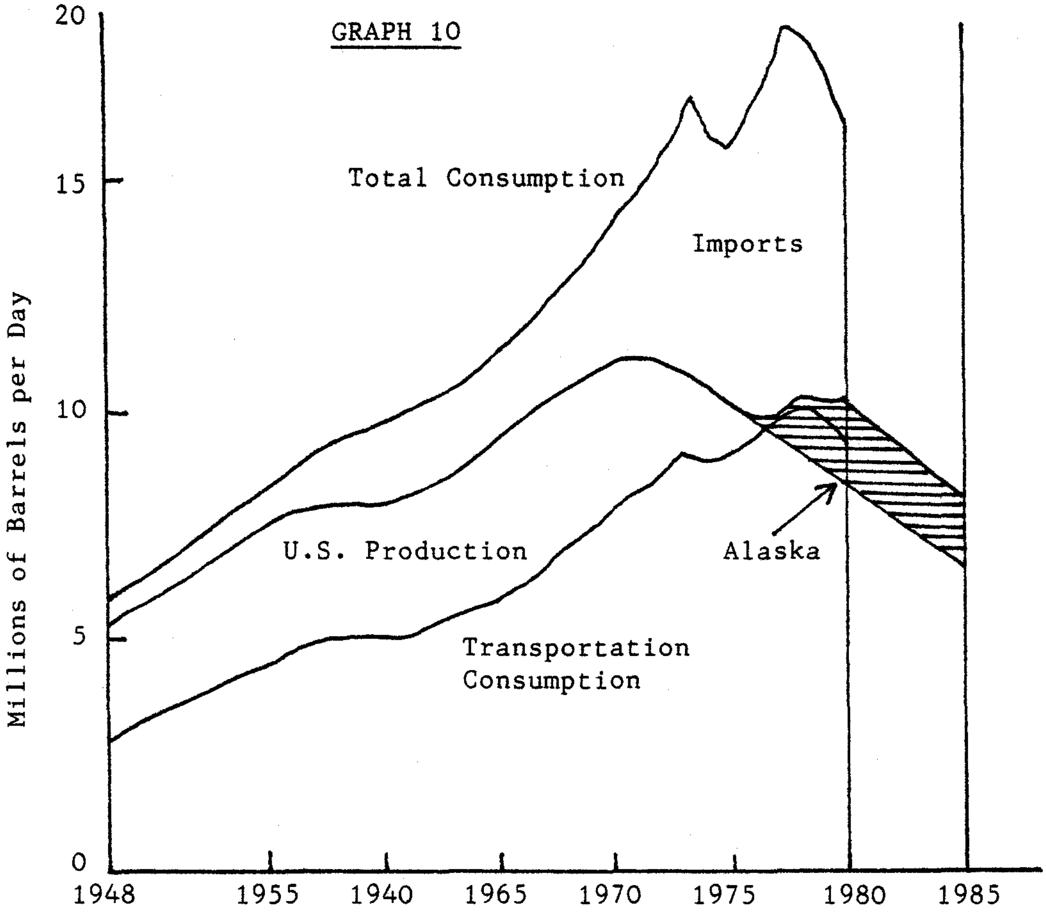
	Resource	Coal 3×10^{19} J		Oil 3×10^{19} J			Gas 3×10^{19} J		
	Cost Category	1	2	1	2	3	1	2	3
	1 (N Am)	174	232	23	26	125	34	40	29
R	2 (SU/EE)	136	448	37	45	69	66	51	31
E	3 (WE/JANZ)	93	151	17	3	21	19	5	14
G	4 (LA)	10	11	19	81	110	17	12	14
I	5 (AF/SEA)	55	52	25	5	33	16	10	14
O	6 (ME/NAF)	1	1	132	27	n.e.	108	10	14
N	7 (C/CPA)	92	124	11	13	15	7	13	14
	WORLD	560	1019	264	200	373	267	141	130

COAL - 1 = cost of \$25/t, 2 = \$25-50/t

OIL, GAS - 1 = \$12/boe, 2 = \$12-20/boe, 3 = \$20-25/boe

A world total of 3.3×10^{22}J is obtained by adding up the categories 1. At the 1975 consumption rate of 8.2×10^{12}W, this supply would last about 130 years. If the consumption rate moves up to the low scenario (see page 30) of 22.4×10^{12}W, the supply would last 45 years. If the high scenario of 35.7×10^{12}W is assumed, then the total fuel supply would last only 30 years. It is this last calculation that resulted in the public's concern about resource scarcity. If all the categories are added a total of 9×10^{22}J is obtained. At the high rate of consumption (35.7×10^{12}W), this amount would last about 75 years. However, if the world consumption can be stabilized at 15×10^{12}W, the total fossil fuel supply would be depleted in about 200 years. If this is the case, then certainly the fossil fuel scarcity is much less tense than it appears today.

Surely fuel consumption rates are decreasing. In the May, 1981 Scientific American, the most recent date for the U.S. oil consumption are given, and the rate has been decreasing for the last three years.

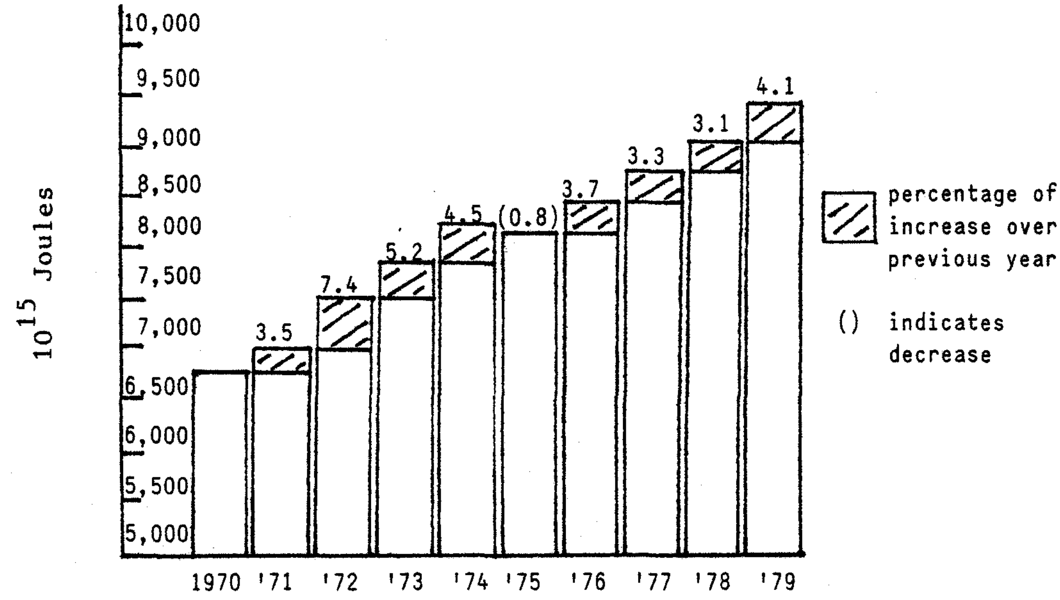


From a high of 18.3 x 10^6 barrels/day in 1975, the consumption has decreased to 16.7 x 10^6 barrels/day. Transportation consumes much of the oil today, and the efficiency of the automobile is increasing yearly, and hence a drop in the oil consumption rate should continue. The rate of decrease over the last three years is about 10%, which could very well continue in the next 20-25 years. This actual reduction is in excellent agreement with the predictions made in the Table on page 31.

However, as a reduction occurs in North America, a corresponding increase in consumption will occur in the other less developed countries.

But Canada's rate of consumption is also still increasing at a rate of 4.5% in 1979, and an average of 4.4% during the years 1973-79.[29] The graph below describes the picture well.

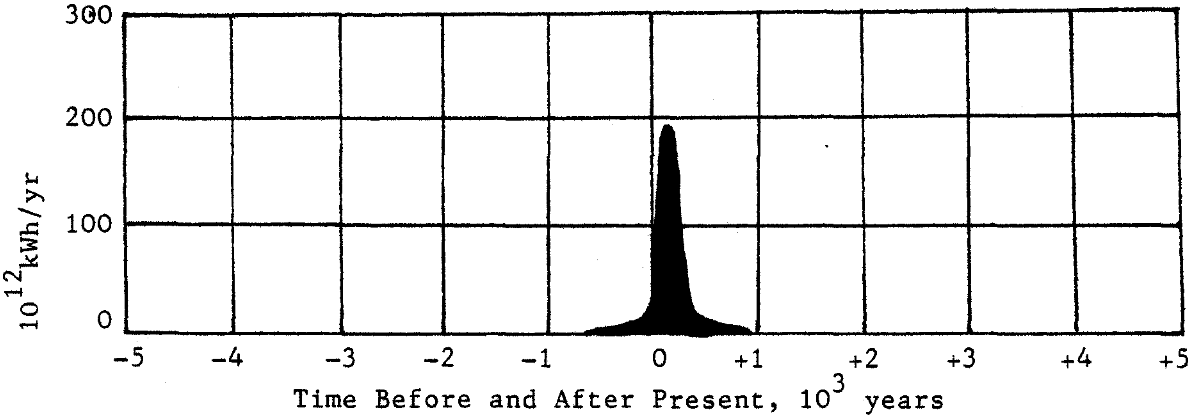
GRAPH 11: Total Energy Consumption Rates for the 1970's For Canada



Hence, it seems feasible to conclude that in the next 50 years, the world's fossil fuels will be depleted. It is interesting to note that wood was used for about 50 years, then coal for 50 years, now oil and gas for 50 years. Will the next 50 years see the rise of nuclear power?

To keep time and energy in perspective relative to mankind's history, the epoch of fossil fuel exploitation is put on a time scale of human history ranging from 5000 years ago to 5000 years into the future. The dramatic result is shown below:

GRAPH 12[30]



Fossil fuels play a very small (but very important) part in mankind's history. The odd-looking projection on this graph is often referred to as "Hubbert's Pimple", since Hubbert was the first one to suggest this graph. Fossil fuels will serva mankind for only a very short period compared to the historical scale. It is a very short period, but a very dramatic one.

VI NUCLEAR RESOURCES

Today's nuclear energy is derived solely from Uranium. The effect that nuclear energy has on the energy crisis depends on several factors: (i) the amount of uranium present, (ii) the rate of uranium consumption, and (iii) alternative methods of using uranium.

The amount of uranium present depends directly on the cost/kg of uranium mined. The International Fuel Cycle Evaluation group suggests 4.3 million tonnes of uranium at prices up to $130/kg are available in the Western World (the Canadian reserve is estimated at about 415 000 tonnes). The World Energy Conference, 1974, gave the following analysis:[31]

Country	Reasonably Assured Resources up to $26/kg Uranium in Thousands of Tonnes	Total Uranium Resources in Thousands of Tonnes
United States	330 000	2 000 000
Canada	190 000	720 000
Sweden	--- ---	310 000
South Africa	200 000	300 000
Australia	120 000	160 000
France	35 000	85 000
Nigeria	40 000	81 000
India	--- ---	62 000
Colombia	--- ---	51 000
Argentina	13 000	39 000
Gabon	21 000	30 000
Rest of Europe	22 000	74 000
Rest of World	17 000	78 000
TOTAL	990 000	4 000 000

The amount of uranium available is closely related to the cost of producing it. Further exploration will also discover more sources--a new deposit was recently discovered in Australia. It seems feasible to have a supply of 20 million tonnes of uranium as a working hypothesis.

The completed and projected nuclear power stations in the Western World require about 100 000 tonnes of uranium/year, which would deplete the 4.3 million tonnes in the Western World in about 40-50 years. This would not solve the energy crisis!

Other types of reactors would make the uranium source last much longer. The CANDU reactor (see Alternate Sources: Nuclear) is a much more efficient reactor than the LWR. If the fast breeder reactor were to be used, the uranium would last virtually indefinitely. But these fast breeder reactors would have to be in operation by the turn of the century.

The "energy crisis" has accelerated nuclear power programmes, but conservation might reduce these considerably. As energy increases, and more and more emphasis is placed on conserving energy, the demand for electricity might decrease--it is easy to turn off lights, to lower the thermostat setting in the hot water tank, to decrease electric heat for space heating, to decrease display lighting, etc. Ontario Hydro has had to decrease its projected electricity demand several times. The development of nuclear power--though restricted--will likely continue and by the end of the century it may provide a considerable amount of energy.

NOTES - CHAPTER ONE

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22. Ibid.

23. *Ibid*.

24. *Ibid*.

25. M.K. Hubbert, *op. cit.*

26. P.R. Odell, "The Future of Oil: A Rejoinder", *Geographical Journal*, June, 1973.

27. G. Foley, *op. cit.*, p. 141.

28. W. Häfele, *op. cit.*

29. *Almanac of Canada 1981*, Don Mills, Ont.: Corpus Publishers, 1981, p. 176.

30. D.N. Lapedes (Ed.), *Encyclopedia of Energy*, N.Y.: McGraw-Hill, 1976, p. 22.

31. G. Foley, *op. cit.*, p. 188.

CHAPTER TWO

ALTERNATE SOURCES OF ENERGY

I HYDROGEN

A. Hydrogen and Electricity

Whenever alternate sources of energy are discussed one must distinguish between energy sources and energy currencies. Gasoline, heating oil, and natural gas are energy sources because they are taken from the ground. These are also currencies because we can carry them about or pump them into required situations. All other energy sources (tidal energy, nuclear energy, etc.) are energy sources, but not energy currencies. We just can't put a nuclear reactor into our home. However, what we can do with these energy sources is to convert them into one energy currency--Electricity. Electricity is the most easily transferred currency but it is very difficult to store. To store electrical energy requires that it be transformed into some other energy currency. A promising storage alternative is HYDROGEN. Very few generating stations work at full capacity except during peak load periods of the day.

In off-peak periods, these stations could be operated at full load if the excess electricity were used to electrolize water into its hydrogen and oxygen components. The hydrogen created in this way can be stored and burned when needed, releasing the same amount of energy that was required to produce it in the first place.

Especially in Canada, nuclear power stations could be set up in Northern locations to produce hydrogen which then could be piped via already established natural gas pipelines to population centers where its combustion energy is needed.

Hydrogen has a great many applications. It may be used for heating, for ore refining processes, for the manufacture of fertilizer, and for the production of hydrogenated foods.

B. Recent Developments

The Billings Corporation,[1] with headquarters in Provo, Utah, has already demonstrated how effective hydrogen can be: for heating homes, driving cars, lighting stores, and operating dryers.

Mercedes-Benz is already producing cars,[2] buses and trucks that use hydrogen as fuel. The combustion of hydrogen yields water as its main product. Trace amounts of nitrous oxide are also produced when air is used as the source of oxygen. However, with today's pollution control devices, this contaminant can be removed from the combustion product so that water is the only product discharged into the atmosphere. Certainly, the carbon dioxide greenhouse effect caused by the burning of hydrocarbon fuel is eliminated.

The National Research Council is actively supporting research with grants totalling two million dollars per year. A Canadian Commons committee on Alternative Energy Sources recommended in May, 1981, that the scale of support be expanded to a billion dollars over the next five years. The Ontario government has recently entered the "hydrogen-fuel" scene with a 10.8 million dollar grant to Professor Scott of the University of Toronto in support of his extensive research programme on hydrogen development. Professor Scott[3] is convinced that hydrogen is the only answer to the energy or fuel problem.

Many other Canadian universities have mounted smaller programmes in this area[4] and Bell Northern is exploring the possibility of solar radiation-induced electrolysis. This effort is part of a world-wide interest in hydrogen as an energy currency, with major efforts underway in Japan, West Germany, France and the U.S.A.

How close is the hydrogen era? In Canada alone, private industry actively supports it, public institutions actively research it, and as stated, provincial as well as federal governments actively encourage it. Major commercial applications could be on the market in ten years, and in perhaps twenty years, hydrogen energy will be in substantial use.

Rising oil prices, which have multiplied the cost of hydrocarbon energy forms at least ten times in the last six years, have made non-fossil based hydrogen energy systems economically attractive. The increasing concentration of carbon, sulphur, and nitrogen oxides in the atmosphere has made the switch to hydrogen extremely attractive. Hydrocarbons are becoming too valuable to burn!

C. Feasibility of Hydrogen as a Fuel

Hydrogen does not have a good "public" image. The burning of the German air ship "Hindenburg" in 1937 with the loss of thirty-six lives created a "Hindenburg Syndrome" in many minds. But an association called the "Hindenburg Society" is actively engaged in demolishing this syndrome. The loss of life in the Hindenburg disaster was not caused by the hydrogen, but by the diesel fuel used to power the dirigible's motors. The hydrogen went straight up as it escaped or burned and caused no harm. Unlike conventional fuels which puddle when they are released from the containment, hydrogen disperses very quickly into the atmosphere. Indeed, the minute size of the hydrogen molecule allows it to diffuse (leak) through solid containers. It also tends to be absorbed in metals and embrittle them. However, satisfactory answers to these technological problems do exist.

To make hydrogen more economically viable, the use of nuclear energy to generate electricity must be increased. Twenty-five to thirty percent of Canadian energy needs are now being served by electricity. To accomplish an increase in electricity production, there must be an effective way to convert electrical energy into chemical raw material and portable fuel for use in cars, trucks, trains, and aircrafts. Hydrogen not only provides that possibility, but it offers other benefits. The electrolysis of water into hydrogen and oxygen is the key to a long-term hydrogen energy system. The Electrolyser Corporation of Canada,[5] in cooperation with Noranda Mines, is building a two megawatt pilot plant for the production of hydrogen. As stated previously, much of the electricity necessary to produce hydrogen could come from excess generating capacity in off-peak load hours.

The efficiency graphs for electric power transmission by high voltage line, and for hydrogen produced through electrolysis (including conversion loss) cross when the power must travel more than 500 kilometres. Beyond that distance, there is a continuing energy loss in a high voltage transmission line, but there is little loss when transmitting hydrogen down a pipeline.[6] And conversion of electricity into hydrogen suddenly makes it feasible to build major hydro power projects at great distances from the population centres where energy is to be consumed. Electricity would be produced by the hydrogen-oxygen fuel cell.

The economic and ecological soundness of a gradual world conversion to hydrogen energy to replace the fading hydrocarbon economy and the world's changing primary energy resource base makes the eventual change very probable. Perhaps it is not a matter of whether or not we will convert to hydrogen energy; it could be a matter of how fast it will happen. The speek of conversion depends on how rapidly the technological developments can be made, and on the proportion of our resources that we wish to expend to effect the transition.

D. Storage of Hydrogen

1. As a Gas or Liquid

At a typical pressure of 136 atmospheres hydrogen gas in a steel container weighs about 30 times more than an equivalent amount of gasoline, and 99% of the weight is in the container. The same container takes up about 24 times more space than a container holding gasoline with an equivalent energy output.

Canadian Liquid Air contains the gaseous hydrogen in a bottle under a pressure of 2200 p.s.i., and one pound of hydrogen is stored in a 125-pound bottle.

Liquefaction of hydrogen requires a major fraction of the energy yielded upon the combustion of hydrogen. Liquid hydrogen is extremely cold--20°K--and it is highly volatile if it is spilled. It requires very sophisticated equipment to store liquid hydrogen safely, and is not a suitable means of using it in the public sector. Metal hydrides seem to be a very feasible alternative.

2. The Storage of Hydrogen as Metal Hydrides[7]

Most metals will form metal hydrides: $M + H_2 \rightleftharpoons MH_2$. Obviously, with the correct temperature and pressure the equilibrium can be shifted to the right to produce MH_2, and by changing the conditions the hydrogen can be obtained. The metal is in the particulate form to increase the surface area.

The main reason why metal hydrides are used to store hydrogen as an energy carrier is that they absorb an extremely large amount of hydrogen. As a matter of fact, more hydrogen can be stored per unit in hydrides than in liquid hydrogen itself. The reasons are as follows:

- (i) at first hydrogen simply is absorbed onto the surface of the metal;
- (ii) some hydrogen molecules form hydrogen atoms which fill the interstitial spaces within the metal lattice structure;
- (iii) as pressure increases hydrogen atoms are forced into the crystal, and the saturated metal moves into the metal hydride phase;
- (iv) as pressure increases further, the lattice may crack exposing new surfaces and holes for more hydrogen storage.

It requires little energy (low pressures and temperatures) for a metal to move into the metal-hydride phase, and hence it requires little energy to extract hydrogen and use it as a fuel. Metal hydrides are very stable and very safe to handle. The metals chosen should be plentiful, economic, and safe, and should evolve hydrogen at a fairly low temperature (below 300°C). These criteria eliminate all known binary hydrides, except one--Magnesium hydride--which is a borderline case. Ternary hydrides are actively studied today and some offer excellent possibilities.

The properties of some represenative hydrogen-storage media are compared in the following table. The gaseous hydrogen in this table is at a pressure of 100 atmospheres. This table shows that one mL of a metallic hydride contains more grams of hydrogen than 1 mL of liquid or gaseous hydrogen itself. Hence 1 mL of a metal hydride will have more energy (calories) than 1 mL of gaseous or liquid hydrogen. However, the table also shows that the energy/weight is by far the greatest for pure hydrogen. This immediately presents a problem for transportation. If a vehicle is to have enough hydrogen for a satisfactory range, then a considerable weight in the form of the metal hydride is added to that vehicle.

TABLE 7

Storage Medium	Hydrogen Storage Capacity		Energy Density	
	By Weight (Percent)	By Volume (Grams per Milliliter)	By Weight Calories* Per Gram	By Volume Caloriesper Milliliter
Magnesium Hydride (MgH_2)	7	.101	2373	3424
Magnesium-Nickel Hydride (MG_2NiH_4)	3.16	.081	1071	2745
Vanadium Hydride (VH_2)	2.07	.095	701	3227
Iron Titanium Hydride ($FeTiH_{1.95}$)	1.75	.096	593	3254
Lanthanum-Pentanickel Hydride ($LaNi_5H_7$)	1.37	.089	464	3017
Liquid Hydrogen (H_2)	100	.07	33900	2373
Gaseous Hydrogen (H_7)	100	.008	33900	271

* the weight is that of the fuel + container

Of the various metal hydrides investigated so far, Iron titanium hydride is a leading contender--it is cheaper than Lanthanum-pentanickel hydride--and has been used successfully by a number of research companies such as Daimler-Benz.

As stated previously, metal hydrides have one major disadvantage when compared with gasoline, and that is their weight. However, they compare well with electric batteries, and if we consider energy densities, the hydrides are better than batteries as shown in the following graph:

TABLE 8

Power Source	Energy Density (Watt Hours per Kilogram	Conversion Efficiency (Percent)	Net Energy Density (Watt Hours per Kilogram)
Lead-Acid Battery	30-50	70	21-35
Lithium-Metal-Sulfide Battery	150	70	105
Iron-Titanium Hydride ($FeTiH_{1.7}$)	510	30	153
Magnesium-Nickel Hydride (Mg_2NiH_4)	1110	30	333
Magnesium Hydride (MgH_2)	2332	30	700
Gasoline	12880	23	2962

As the figures show metal hydrides lay far behind gasoline, but are competitive with electric batteries.

The energy picture will surely change over the next fifty years, and hydrogen will play a key role in this change as a carrier of energy and as a raw material for a variety of synthetic fuels. Rechargeable metal hydrides will play a key role in the hydrogen energy economy, and undoubtedly many applications of metal hydrides will be developed as governments and industries emphasize its importance.

Note: The largest single use of hydrogen in Canada for many years to come is to upgrade our heavy crudes, oil sands, and perhaps eventually the coals, lignites and peat. This process of upgrading requires much hydrogen, but by the upgrading of the heavy crudes, etc., the hydrogen is stored in the most convenient form; namely, liquid hydrocarbons. Much research and development remains to be done in this area, and the Federal government is actively supporting work in upgrading the heavy crudes by hydrogenation.

E. Alternate Sources of Hydrogen

1. Photosynthesis

Nobel laureate Melvin Calvin[8] has produced synthetic chloroplasts, which isntead of combining hydrogen with carbon dioxide to form a carbohydrate, produce hydrogen in the form of a gas. Natural chloroplasts are about 4% efficient and degenerate quickly. Artificial chloroplasts last much longer and can produce hydrogen much more efficiently, perhaps up to an efficiency factor of 30%. An important by-product of this artificial photosynthesis is atomis oxygen rather than molecular oxygen, which has many industrial uses, and photosynthetic farm factories might become economically viable.

2. Electrochemical[9]

The electrolysis of water has two disadvantages: a high electric potential is required to drive the reaction, and molecular oxygen is a by-product which is a relatively cheap substance.

The following reaction might be better to produce hydrogen:

$$SO_2 + H_2O \longrightarrow H_2SO_4 + H_2$$

The electric potential to sustain this reaction is about three times smaller than that for the electrolosis of water, and sulfuric is a more valuable product than oxygen.

Hydrogen sulfide is another hydrogen resource that is not utilized. Hydrogen sulfide can be converted to hydrogen and sulfur.

However, if a truly "hydrogen" economy is to be developed water will have to be the source of hydrogen, since the above-mentioned two processes would not be able to meet the demand for hydrogen.

II SOLAR ENERGY

A. From Sun to Earth

The energy transmitted from the sun is in the form of electromagnetic radiation with wavelengths varying from 1 nm to 30 km. The major portion of the energy is in the spectrum of visible light ($4 - 8 \times 10^{-7}$m). The pathway of solar radiation from the sun to the earth's surface can be demonstrated in the following diagram. The number 1 353 W/m^2 is called the solar constant and is that amount of energy received by a surface area of 1.0m^2 positioned above the earth's atmosphere and placed perpendicular to the sun rays.

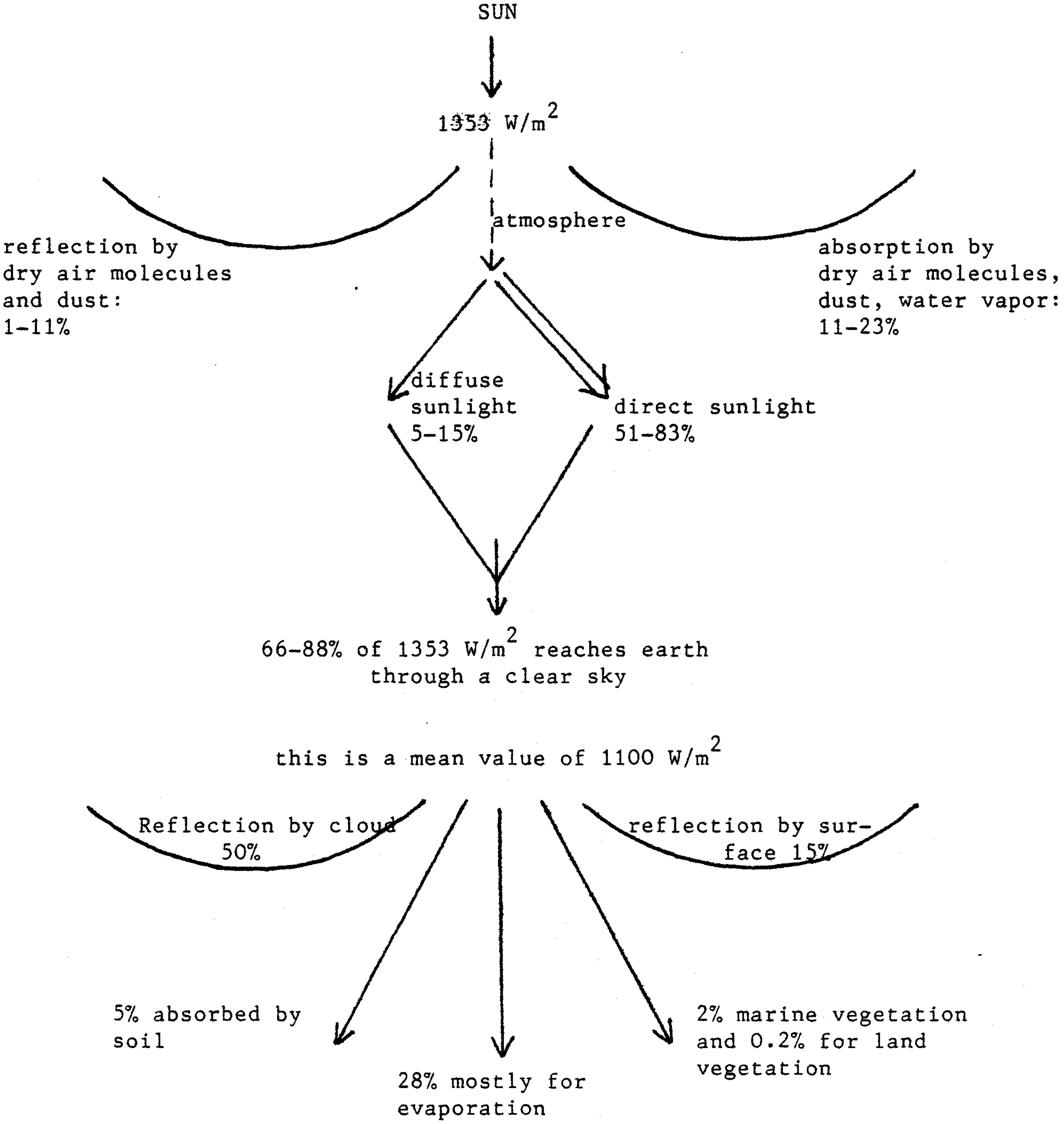
Hence, the earth receives about 550 W/m^2 (50% of 1100 W/m^2) or

$$\frac{550\text{J}}{5\text{ mm}} \times \frac{3600\text{S}}{\text{h}} \times \frac{12\text{ h}}{\text{day}} \times \frac{365\text{ d}}{\text{year}} \times \frac{\text{x } 6.38 \times 6.38 \times 10^{12}\text{m}^2}{\text{diametrical plane of earth}}$$

$= 3 \times 10^{17}$ kWh/y or 3×10^{8} TWh/y which is an enormous amount. Häfele suggests that approximately 3 TWh/y might conceivably be used by the year 2030. The 0.2% of solar radiation absorbed by land vegetation is also a large amount. Indeed, until the exploitation of fossil fuels began about 300 years ago, it was far in excess of man's needs. Today, with burgeoning population and a ten to twenty fold increase in the per capita use of

DIAGRAM 4

A Pathway of Solar Radiation Towards the Earth

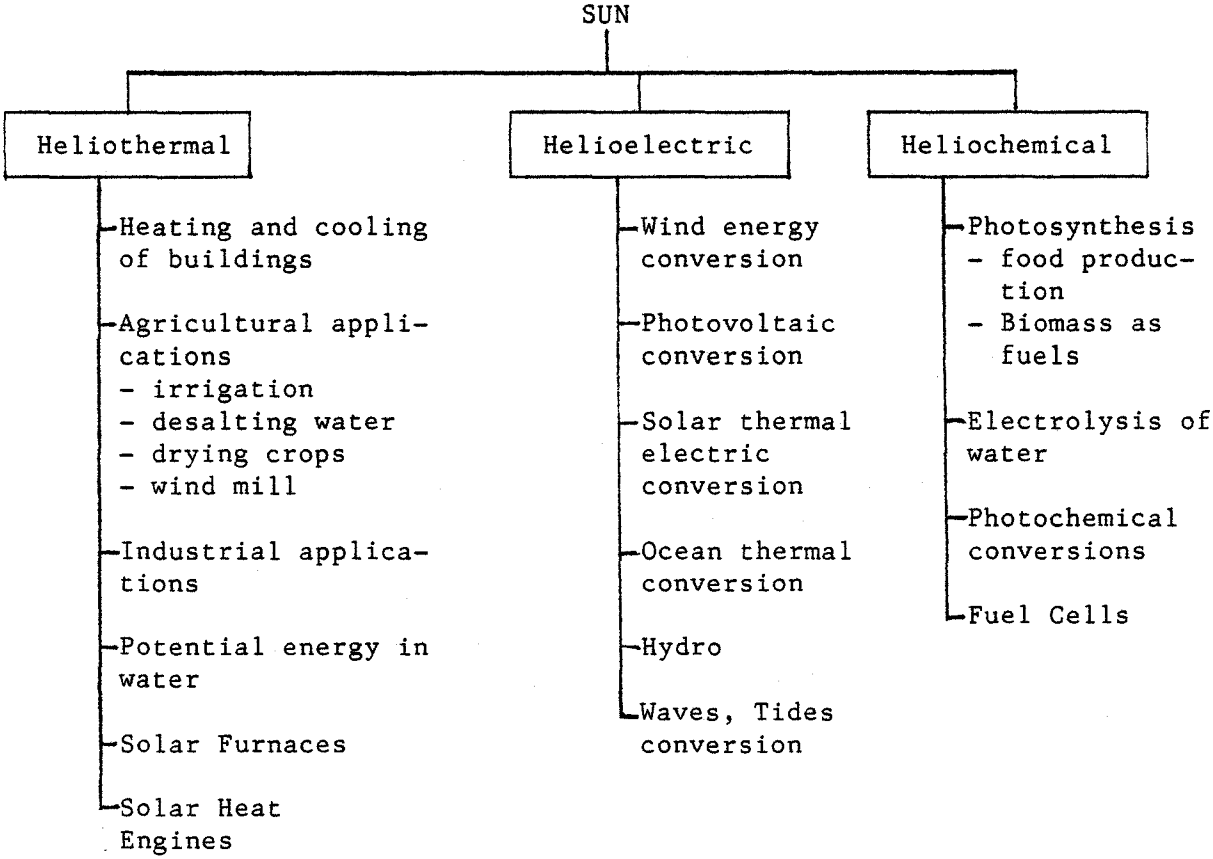


energy, 100% utilization of this amount (which is patently impossible) would fall short of the demand.

B. Uses of Solar Energy

Solar energy can perform useful work in a number of ways, and one possible classification of these is given in the following figure.

FIGURE 3



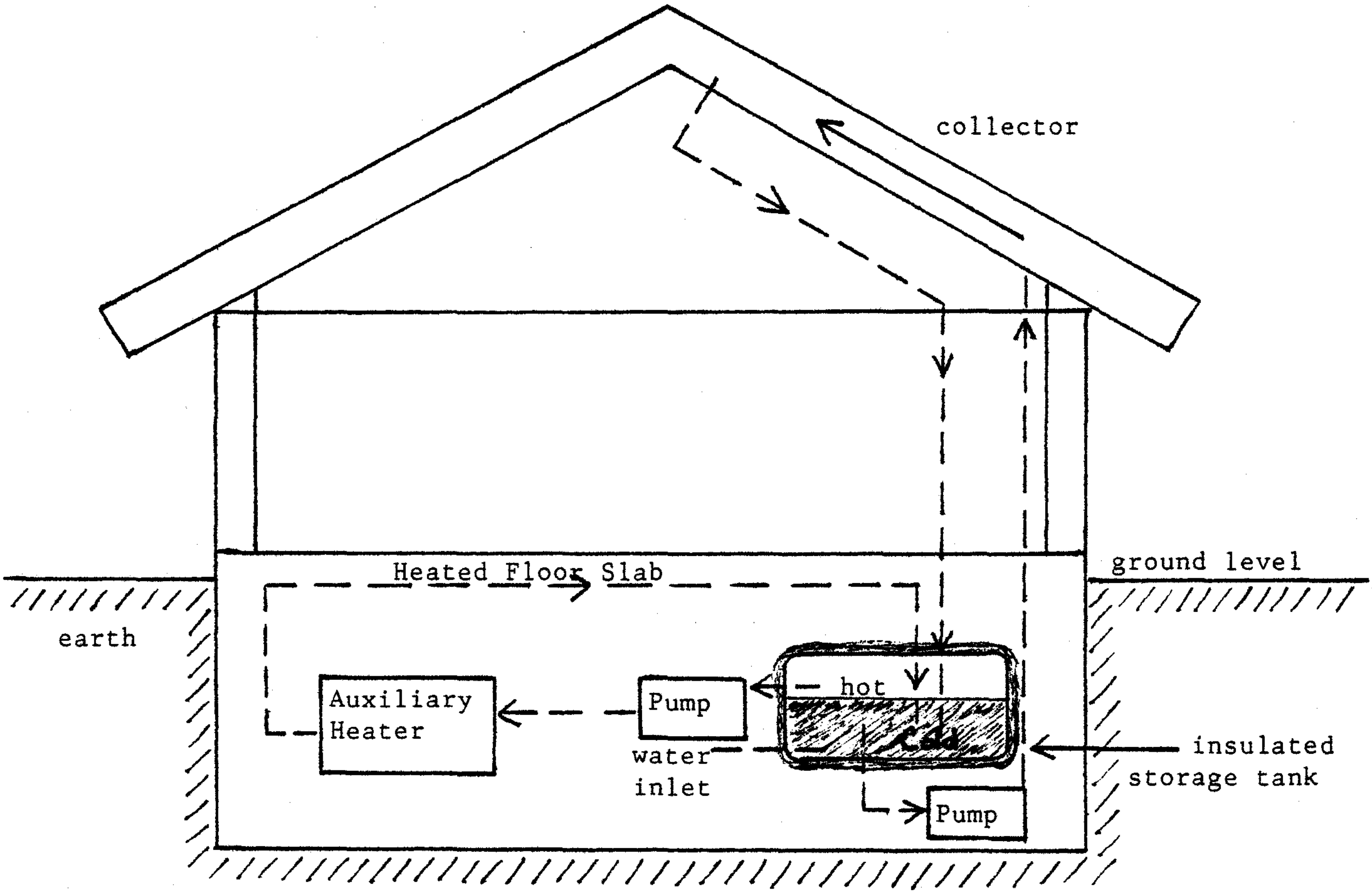
As can be seen from the above diagram, solar energy can have many applications, but it has two disadvantages: its low concentration, and its irregular availability due to its diurnal cycle, seasonal and climatic changes.

A number of applications are now discussed in detail.

1. Solar Home Heating

There are two basic types of solar heating systems: passive solar systems--where the building itself collects and stores heat--and active solar systems--where a separate heat collection, storage, and distribution system is attached to the building. The south-facing roof can collect enough radiant energy in the Northern Hemisphere in a day to heat a house for 24 hours during the winter if the conditions are favourable (i.e., enough sunshine during the day). The roof must be covered with some suitable solar radiation absorber, there must be some type of conveyor system to distribute this energy throughout the house and there must be an adequate storage system to cover the night and cloudy days. A simplified schematic[10] diagram below shows the basics involved:

DIAGRAM 5



The most commonly used collector is a series of pipes containing water, which are mounted on flat, black, metallic plates, covered by sheets of glass. This arrangement gives a "greenhouse effect" in which the collector absorbs radiant energy and transfers it in the form of heat to the water in the pipes. The heated water can then be pumped to radiators, and excess heated water can be stored in tanks beneath the building, or basement of the house. Usually an auxiliary heater is installed as a back-up system. For a solar heated home, the commonly used "flat" collectors are usually mounted on a steeply-angled roof, the angle of which is determined by "local latitude plus 10 degrees" to improve winter efficiency when the sun is lower on the horizon.

Because solar energy is of very low concentration, a large surface area of collectors is required. A recent building study by the National Research Council of Canada states that a collector area of about 1/3 to 1/2 the floor area of the home's living space is required to absorb enough solar radiation to satisfy even half the heating requirement of the home. Another disadvantage is the cost of installation. At present, it costs \$6000 - \$8000 for a \$60,000 house to install a partial solar heating system to supply 50% of the heating requirement. However, as research continues, and more efficient collectors and better storage systems are devised, the cost might be reduced, and solar heating might become a more promising alternative.

Ontario's solar energy programme aims to meet 2 per cent of Ontario's energy requirements by 1995. This amounts to enough energy to heat 700 000 homes.[11] The recently announced Solar Energy Strategy for Ontario provides \$50 million over five years to help the private sector develop cost-effective and reliable solar equipment. A number of active solar demonstration projects are in operation in Ontario as field studies, of which Mohawk Laundry in Hamilton is one.

2. Wind Power

(a) Introduction

Wind power harnesses the kinetic energy in the earth's atmosphere to perform useful work. The kinetic energy, of course, is produced by the solar radiation. Total global atmospheric wind power is about 10^{14} kW, or 10^{17}J/s. If practical wind generators covered the whole land mass, one could conceivably extract as much as 10^{13} W of energy per year worldwide. Since low wind velocities are very inefficient, and not all of the land mass will be covered with wind generators, a 10% efficiency factor seems reasonable, which yields a world supply of 10^{12} W or 1 TW of power. Häfele suggests a theoretical maximum of 3 TW but a practical maximum of 1 TW, which represents 5% of the world-wide energy demand.

Wind power has lifted water for centuries, and has produced electricity in rural areas for many years, but the demand for more powerful motors saw a rapid decline in wind power in the last 30 - 40 years. However, our exponential appetite for energy has created a new interest in more efficient and more powerful wind-powered machines.

(b) Wind-Generated Electricity

Wind generators and storage systems of various sizes can be bought today. In strong winds, the cost of producing electricity compares favourably with conventional methods, but as wind velocities decrease, the costs increase sharply. It has been estimates that if all wind were used in the U.S. it could produce 2 x 10^{12} kWh of electric energy, equivalent to the total 1975 U.S. electricity consumption.

The world's largest windmill was recently completed at Boone, North Carolina, with two 30-m blades mounted on a tower 44 m high. In winds of 10 m/s and up (the so-called "energy wind") it can supply one megawatt of electricity. Because of the extreme dependence of available power upon wind velocity, and because the average wind velocity at most major American cities is about 4.5 m/s, 5000 such windmills, none lying in the wake of the other, would be required to produce as much power as an ordinary one gigawatt (10^9) power plant. The U.S. would need 130,000 such windmills to make a 1% contribution to its power needs.[12]

The amount of theoretical wind energy in Canada is enormous, but it is very unevenly distributed--much more so than solar energy because wind energy is proportional to the cube of wind speed:

$$E_k = KDV^3,$$ where

K = density of air
D = sweeping blades' area
V = average wind speed

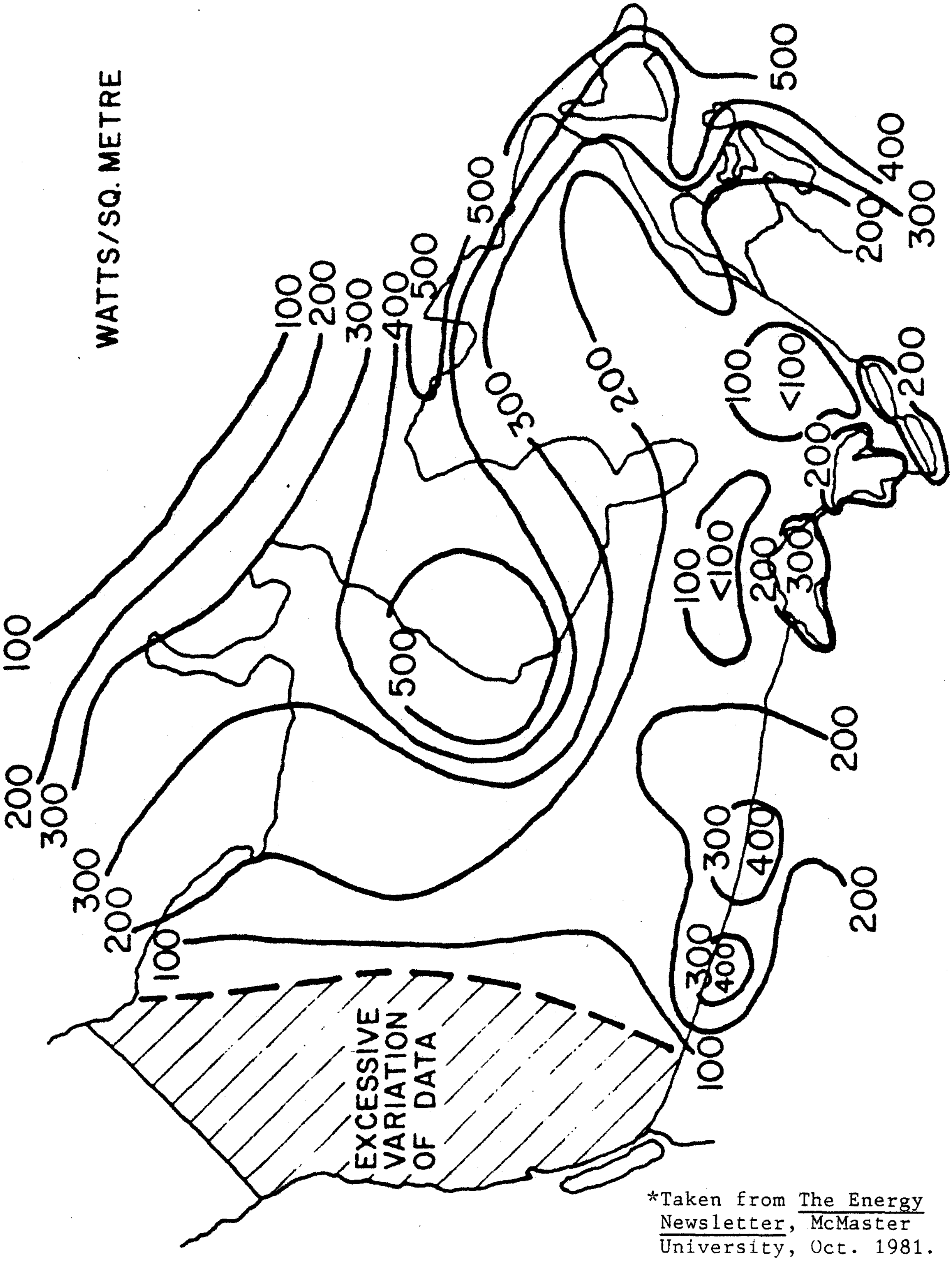
The following figure shows the distribution of the wind's kinetic energy per 1 square metre of vertical surface area at an altitude of 30 m. The greater the value of the E_k, the cheaper the cost of electric energy produced. But the cost will be relatively high in low wind velocity which occurs at the more populated areas of the country. Even though these figures from the diagram seem low at first glance, a large enough surface area can indeed supply much energy.

According to the NRC (Ottawa) low plant density criterion (0.1% of land area occupied by wind generators), and a conversion efficiency of 15%, a total of 130,000 megawatts could be produced, which is approximately the amount of electric power consumption in all of Canada last year.

In Ontario, the average winds are light: 5-6 m/s, or about 100 W/m^2. A wind generator requires a cut in wind velocity of about 4 m/s.

DIAGRAM 6*

Annual Average Wind Power Density at 30-metre Height, in Watts per Square Metre



*Taken from The Energy Newsletter, McMaster University, Oct. 1981.

Hence, it appears that sufficiently high wind velocities occur only in the coastal areas of the Great Lakes and James Bay. The Ontario Government has constructed and operates a 50 kW wind/diesel hybrid system in the Sudbury area. The project is to run for two years. Ontario Hydro is testing the integration and control of small wind generators in the grid.[13] The Federal Government is funding, in conjunction with Quebec Hydro, a 3.8 Megawatt generator, shown in the following diagram.

Mode of Operation of the Darrieus Rotor

The Darrieus windmill is a vertical-axis machine which effectively intercepts a large area of wind with a small blade area because the efficient air foils rotate very rapidly. The blades are curved and attached to hubs at the top and bottom of the vertical axis to make it look like a giant egg beater.

The flow of air over an airfoil gives rise to two forces called the life force, which is measured perpendicular to the air flow or relative wind and the drag force which is measured parallel to the relative wind flow. This can be demonstrated in the following diagram:

DIAGRAM 8

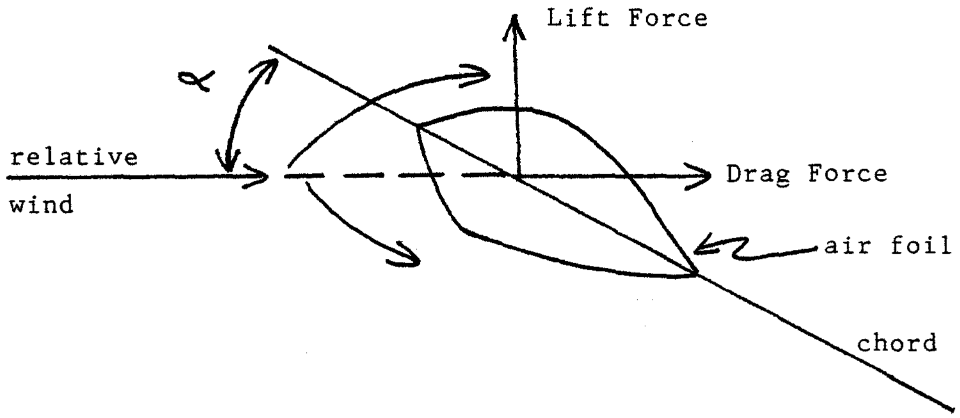
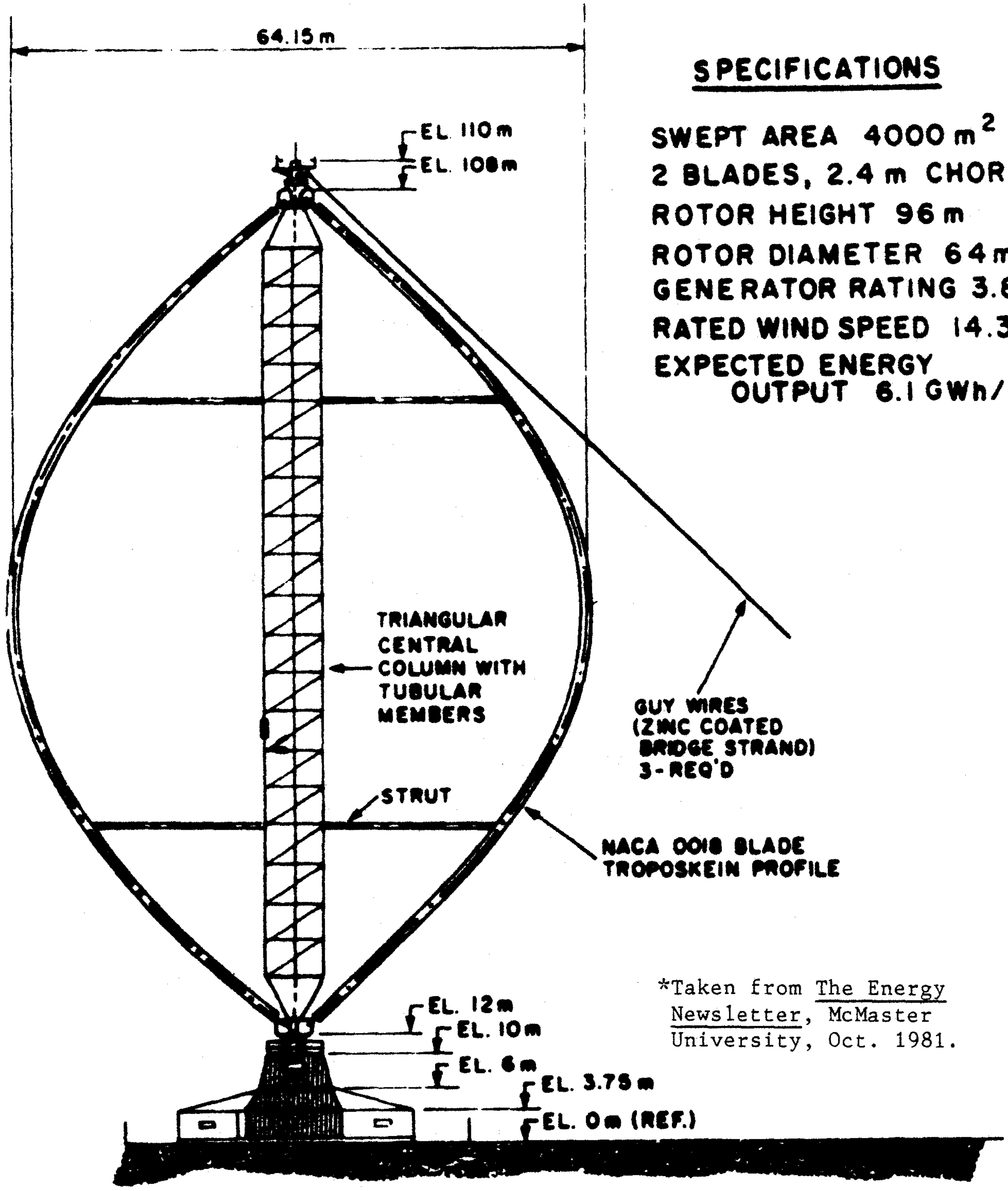


DIAGRAM 7*

Hydro-Quebec-NRC AEOLUS Project
World's Largest Vertical Axis Wind Turbine

AEOLUS



SPECIFICATIONS

SWEPT AREA 4000 m^2
2 BLADES, 2.4 m CHORD
ROTOR HEIGHT 96 m
ROTOR DIAMETER 64 m
GENERATOR RATING 3.8 MW
RATED WIND SPEED 14.3 m/s
EXPECTED ENERGY OUTPUT 6.1 GWh/YEAR

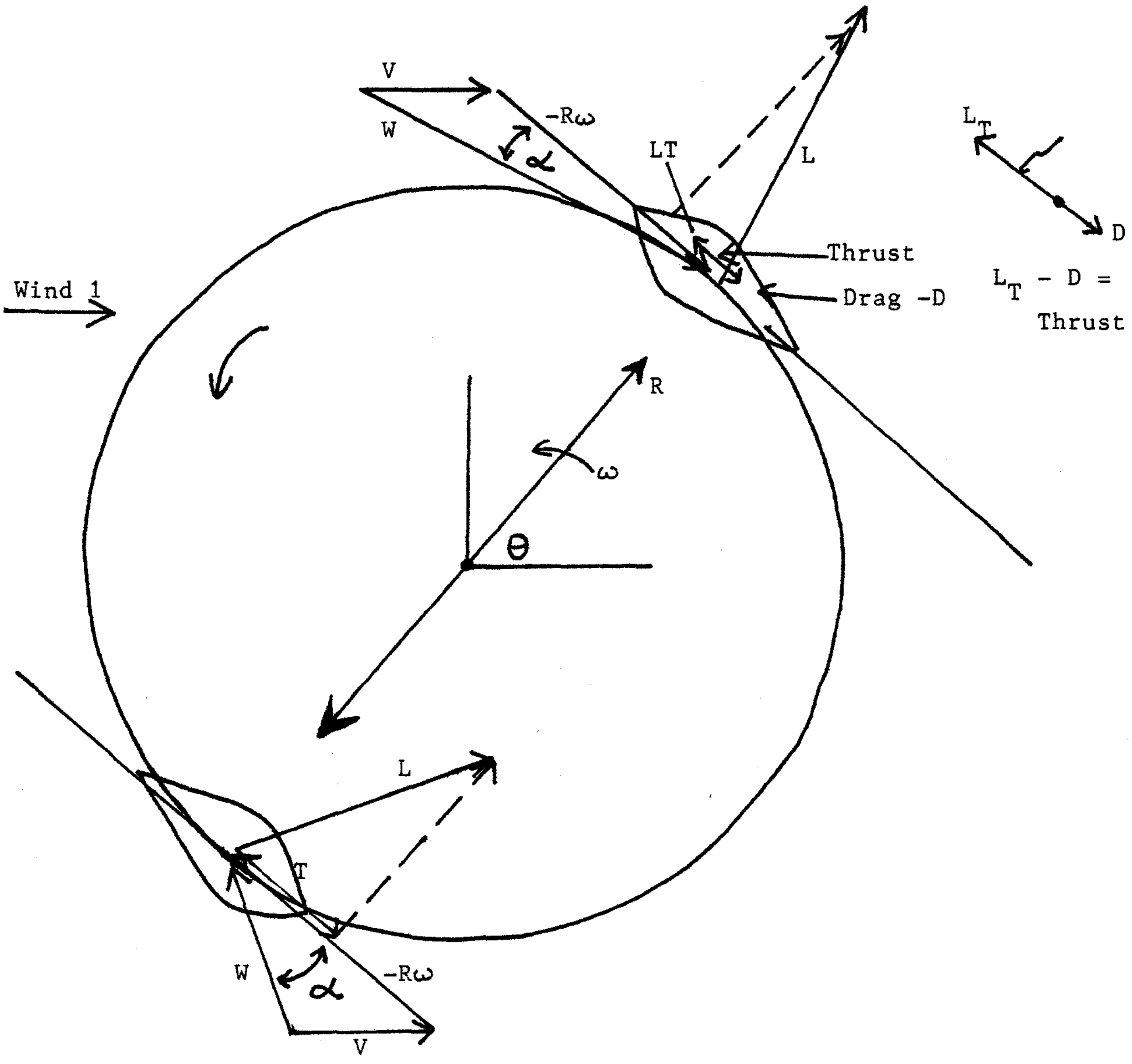
*Taken from The Energy Newsletter, McMaster University, Oct. 1981.

The force of lift can be explained by Bernoulli's principle. The air mass flows with a greater velocity over the top surface of the air foil than over the lower surface. Hence there is less pressure exerted on the top than on the lower surface, and the lift force acts upwards as shown in the diagram. The drag force might be stated simply as air resistance or friction between the air foil and air.

All air foils require some angle with the wind to produce lift. The angle is measured between the wind direction and the chord line of the air foil. The angle is referred to as the angle of attack and is labelled as α in the above diagram. The greater the angle, the greater the lift. However, at a certain angle, the air flow breaks up and the lift stops increasing, and the air foil might stall since drag does keep on increasing. This is important in the Darrieus rotor since at high wind speeds the rotation speed is controlled, and no mechanical device is required.

The air foil of the Darrieus rotor lies along the circumference of the circle it travels, and the air foil is symmetrical about its own chord--if not, the thrust would be favourable going in one way but unfavourable going the other way. Indeed, it is remarkable that the Darrieus rotor works at all. It does rotate because the lift forces are larger than the drag forces and the lift results from the interaction of the blade and the relative wind which is the resultant--or vector sum--of the natural wind and the induced wind caused by the blade rotation. The relative wind keeps changing direction as the blade moves around the circle and so does the lift force on the blade, which is always perpendicular to the relative wind. The interactions and forces of a two-blade rotor are shown in the following diagram:

DIAGRAM 9



The rotor has a radius R and an angular speed of ω. The speed of the edge of the rotor is $R\omega$, and the rotational wind speed is $-R\omega$. The natural wind speed is V. The relative wind speed W is the vector sum of V and $-R\omega$. D is the drag force. L is the resultant lift force due to the difference in pressures exerted on the top and bottom surfaces of the air foil (Bernouilli's Principle). The lift force has a component force tangential to the circle of rotation--i.e. in the proper direction to drive the blade forward, against the natural wind at the 1 position. The forward force depends on the blade already in motion, and the Darrieus rotor is therefore not a self-starter.

(c) Problems to be Solved

If a serious attempt is made to use wind-powered generators, certain problems must be faced by society. The large windmills make noise, so that they should be away from urban centers. Many high wind towers also could interfere with electromagnetic signals (T.V. and radio). And would an array of towers not be an eyesore on the landscape? Much land would be necessary to build the array of towers. A high density of windmills might also cause atmospheric and climatic disturbances as energy is extracted from the atmosphere. However, the density factor proposed by the NRC probably will keep these disturbances small enough to be considered negligible. Public safety must also be considered. Large windmills are vulnerable to damage inflicted by sporadic high winds of hurricane proportions that can occur in intense storms. To make a grid or array of wind towers effective, an adequate storage system better than any now technologically possible must also be established.

3. Hydro

(a) Hydroelectric Generators

As noted before, a large percentage of the solar energy is used to evaporate water and to raise it to higher altitudes, and hence increase its potential energy. Hydropower has two distinct advantages over wind power: water is much denser, and its energy is more concentrated. Water power has been used for many centuries, and is still used extensively. The immensely vast James Bay project in Quebec is an example, as well as

Niagara Falls in Ontario. But in Ontario, only 29.1% of the electricity generated comes from hydroelectric power, and because the total demand is increasing, it is expected that this proportion will drop to 20.3% in 1995.[14] At present, 14% of electricity in the U.S. is supplied by hydroelectric generators, which represents only a 1.4% of contribution to the total energy used.

In Ontario, untapped hydrosources could add another 3750 MW (10^6W) annually, compared to 1815 MW from Sir Adam Beck-Niagara generating stations No. 1 and No. 2, of which the most significant part (2450 MW) lies in the Severn and Albany rivers. These sites are not being developed because of their distances from markets. This is a problem that presently eliminates development of much hydro-powered electricity in Canada, U.S. and Europe. In Ontario, there are 17 sites being investigated, which could supply 500 MW annually, and the provincial government has established a target of an additional 500 MW of hydro electricity by 1995.[15]

Approximately 2% of the world's power consumption is supplied by water power. In Europe about 23% of available waterpower is used, and in North America about 22%. Obviously, the rest of the world either has no water power or has not yet developed it. The U.S.S.R. and China are actively developing hydroelectricity, and there are great unused hydro electric sites in New Guinea, Africa, South America, and Greenland. The James Bay project should again be mentioned here.

There are some very compelling reasons for generating electricity by water power. First, the reservoir is continually refilled by actions of the sun. Second, it is a highly concentrated energy source compared to wind and is much more reliable. Third, it is a renewable energy source.

Fourth, it can be regulated easily. Fifth, it has a conversion efficiency of about 80% compared to a 30% efficiency for a steam turbine. Sixth, it does not produce air pollution. It is possible to increase the hydroelectricity output by a factor of ten, which would mostly benefit the less developed countries.

There are also some disadvantages to consider. The potential sites are usually far removed from markets, thereby creating a considerable transportation loss. The construction of new sites also requires a substantial capital layout

Large dams often involve flooding arable land and nearly always have a dramatic impact on local ecology. Dams create problems for migratory fish, destroy animal habitats, and alter scenic areas. The lakes created by the dams are valuable resources for recreation, flood control and irrigation. Silting may be a serious problem in some cases. For example, the Colorado river is a muddy river and deposits a large amount of silt into Lake Mead. Some twenty-five years ago, realization that the lake would be silted by the end of this century created a good deal of concern. In response, amny small dams were built upstream in the Colorado and its tributaries to settle out the silt before it reached Lake Mead. With these changes, it is now expected that Lake Mead can provide power for more than 500 years.

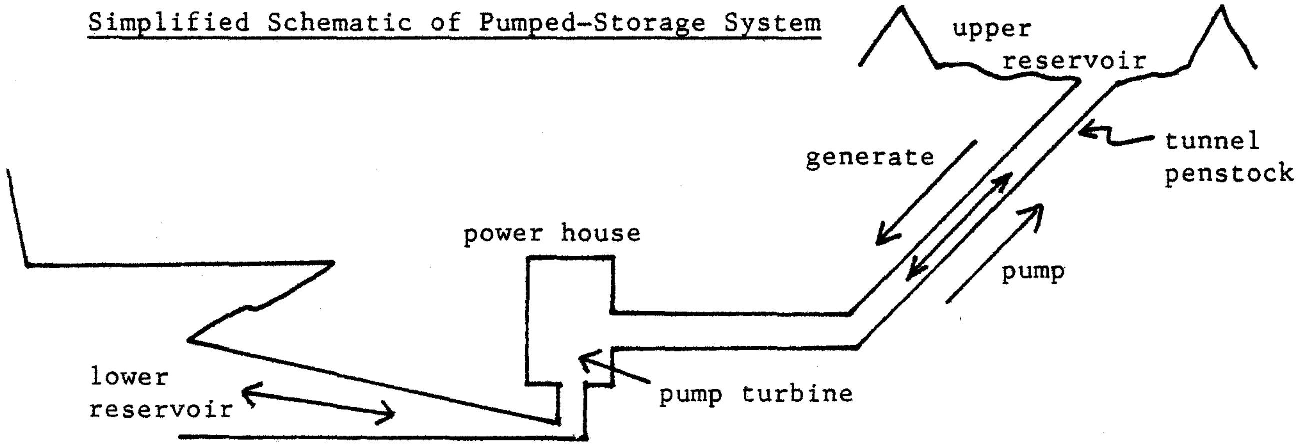
Häfele realistically suggests that hydroelectricity power can be increased by a factor of three (rather than by 10) by the year 2030.

(b) Pumped Storage Systems

A significant development of the 1960's was a rapid increase in the number of pumped-storage hydroelectric systems. In these, water is pumped to a higher elevation by reversing the hydraulic turbine and generator during periods of low demand. In this cycle, the generator becomes a motor driving the turbine as a pump. The energy stored in this cycle can then be used at times of peak demand. Pumping the water uphill costs little since the turbines must run 24 hours a day anyway, and the unwanted energy is stored until needed as potential energy. A simplified schematic of a pumped-storage system follows:

DIAGRAM 10

Simplified Schematic of Pumped-Storage System



A good example of a pumped-storage system is the Niagara Falls hydroelectric system. A large lake at Queenston is pumped full every night to make more energy available during the peak periods of the day.

The following two diagrams show the outline of the Niagara system and the U.S. system on the east shore of Lake Michigan.

(c) Ocean Thermal Gradients

The water temperature within the ocean decreases with depth, and this temperature gradient can be in principle made to supply electric power. The greatest temperature gradients occur at latitudes 10°N and 10°S, where temperature differences of 20-23°C can be attained without going to excessive ocean depths. For a practical device to work, the area must be free of strong wind and water currents.

DIAGRAM 11

Sir Adam Beck-Niagara
Generating Stations
No. 1 and No. 2

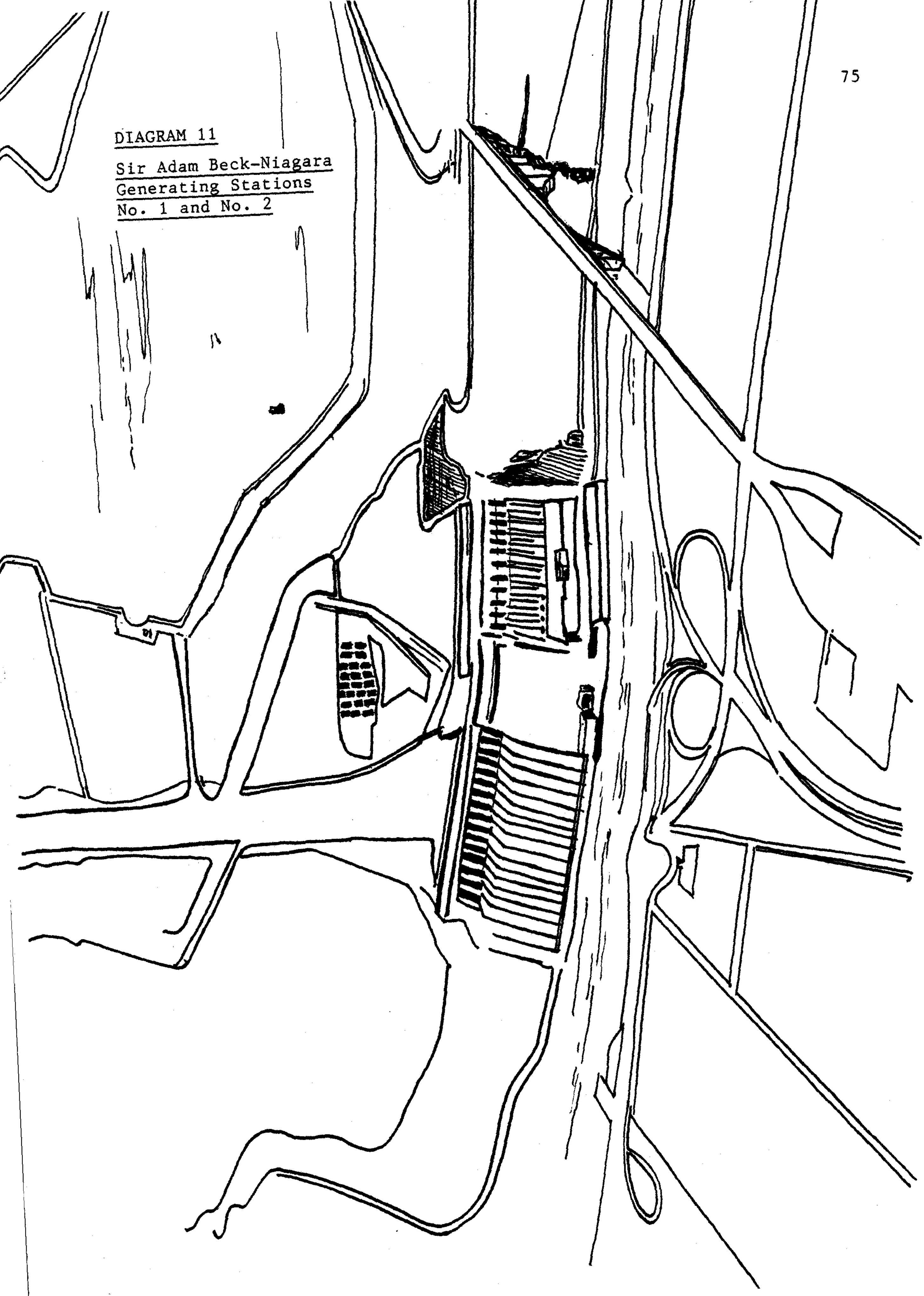
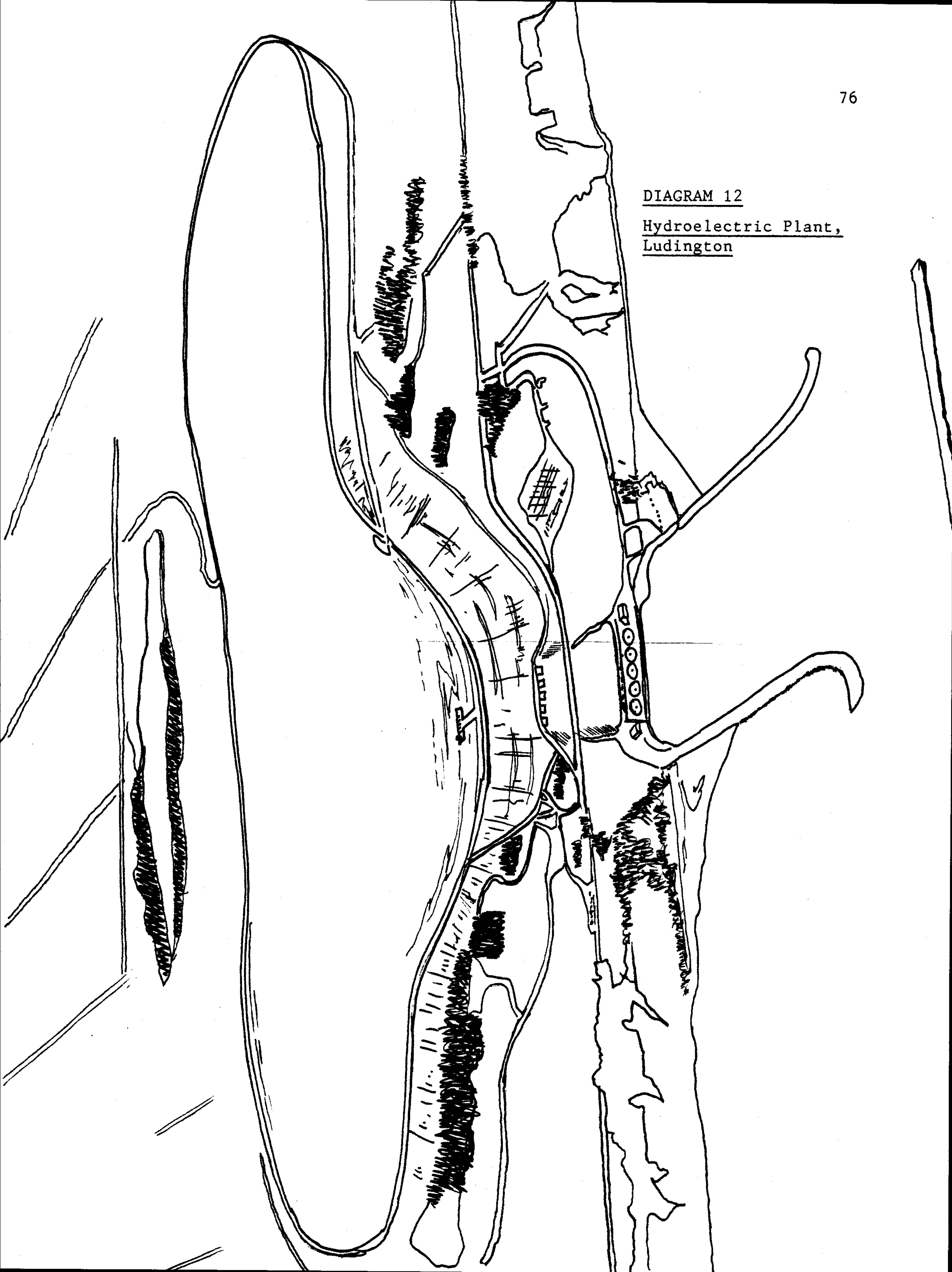


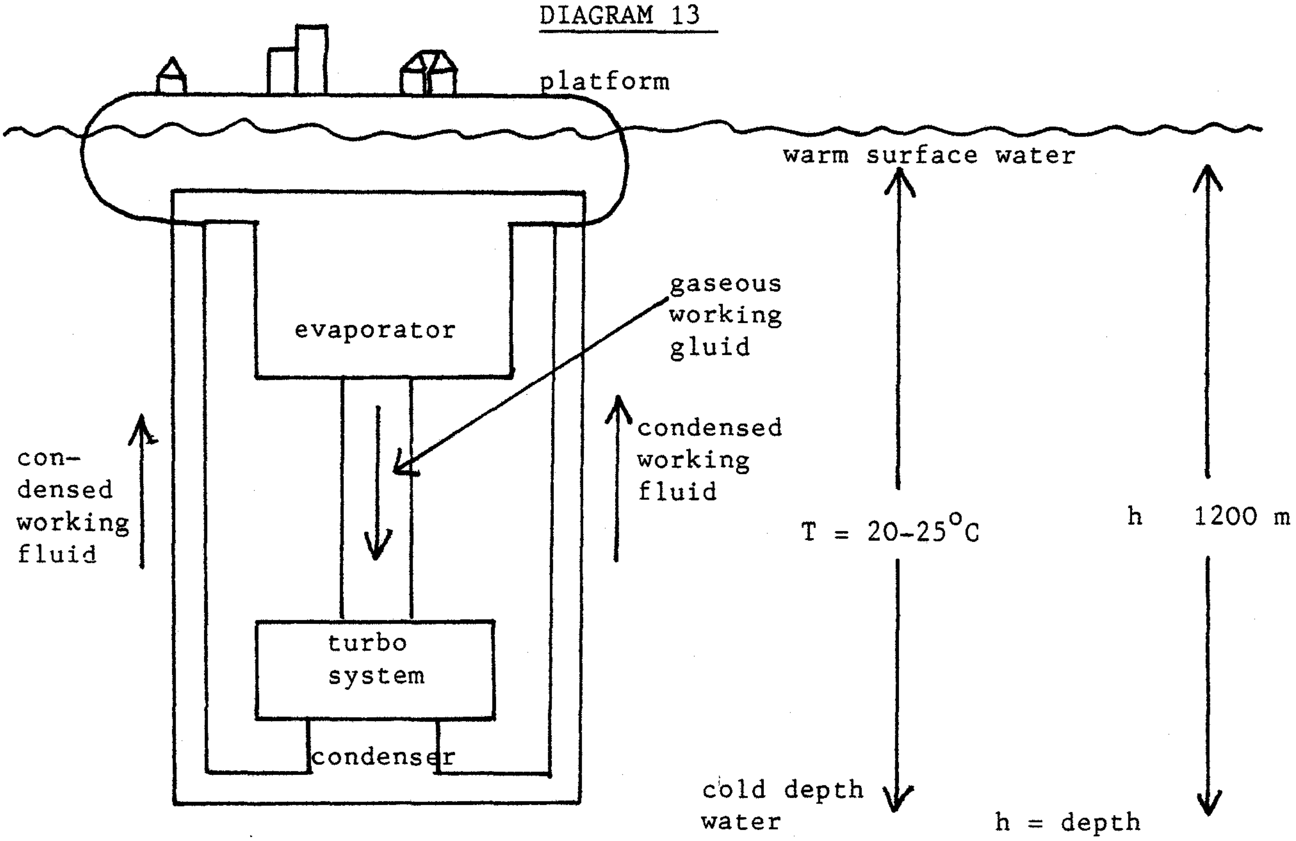
DIAGRAM 12

Hydroelectric Plant, Ludington



A French physicist, Jacques d'Arsonval, first proposed a thermal gradient system in 1881, and his ideas were put into practice by Georges Claude, a student of d'Arsonval, in 1930. The system is known as ocean thermal energy conversion, or OTEC for short. Because Claude's original pilot plant off the coast of Peru generated only 22 kW and was soon destroyed by heavy waves, interest in this idea quickly waned. In 1964, the American J. Hilbert Anderson became interested in it again. In 1976 OTEC received $8 million for research. There are a number of designs for OTEC, but they all operate on the same basic principle. A "working" fluid such as ammonia is heated and evaporated in the warm surface water and ducted to an underwater turbine, where the gas is allowed to expand, driving a turbogenerator system, and is then condensed in the cool depth-waters. The condensed gas is then returned where it warms up to allow the cycle to be repeated. It thus very closely resembles a closed Rankine cycle.

DIAGRAM 13



The electricity produced is transmitted ashore by wire. Hydrogen, oxygen, and fresh water could also be produced by OTEC, but electricity is the primary product.

The efficiency of the system cannot exceed $\frac{T_w - T_c}{T_w}$, where Tw and Tc are the warm and cold temperatures in Kelvin degrees. Thus the efficiency cannot be greater than $\frac{25}{300} \times 100 = 8\%$. In practice, it will be considerably less than this, and hence not a very efficient system.

Häfele considers the potential energy obtainable from OTEC systems on the global scale to be very small, about one half as much as wind power can contribute. In addition to being a very low efficiency device, it demands a very advanced technology and may have serious ecological byproducts. No one yet knows what effect a massive disturbance of nature's thermal ocean currents would have on the teeming fish life of these tropical waters or on the total climate of the earth. It could even alter the direction of such ocean rivers as the Gulf Stream with dramatic effects on countries such as Iceland or England.

4. Biomass

Through the process of photosynthesis, plants capture the sun's energy and use it to combine carbon dioxide taken from the air with water to form a simple sugar:

$$6\ CO_2 + 6\ H_2O \xrightarrow[\text{sunlight}]{\text{chlorophyll}} C_6H_{12}O_6 + 6\ O_2$$

This sugar is then available as an energy source. The energy stored in this manner is very large on a global scale and so "biomass" as an energy source must be taken seriously. Indeed, up to the beginning of the industrial revolution, it was almost the only source of energy available to mankind. In normal jargon, the biomass resource is expanded to include the energy that can be obtained from garbage or the decomposition of biological materials. Wood is the biomass material most commonly used as an energy source. Approximately 15% of the world's energy is still supplied by wood--in the form of the 2300 million tonnes of wood per year used as fuel.

Ontario hopes to increase its energy production from biomass from 8 to 35 million barrels of oil equivalence. This must be placed in perspective in relation to Ontario's annual energy consumption of 560 million barrels of oil equivalence. Thus at present, this biomass source, which includes Municipal solid waste, Mill and bush residues, agricultural crops and waste, amounts to less than 2% of our requirements. To increase this contribution by over four-fold in a few years will be quite difficult. A number of experimental programmes have been begun. the WOODEX method is described in two booklets put out by Shell: Woodex: The Refined Biomass Fuel and Energy From Biomass (February, 1980). (Both of these booklets can be obtained from the Shell Group upon request.) Several "tree farms" have also been started, and attempts to increase the rate of tree growth are being made. It has been shown that in our climate, some trees can reach maturity for fuel in 8-10 years without requiring heavy fertilizers. The Woodex booklet mentioned above (published by the Royal Dutch/ Shell Group) gives an extensive overview of "Energy from Biomass".

5. Wave Energy

While the total energy stored in water waves is quite considerable, the energy concentration is much lower even than in winds and waves offer little promise as a major energy source. The average power available from waves is 30 MW per kilometer of coastline. If one assumes that one could achieve a 30% efficiency in producing energy from these waves, one would get about 10 MW/km. If wave generators were to line the entire 5000 km of coastline of the U.S.A., one could in principle produce 50,000 MW of power. This total is about 2% of the total annual U.S. energy consumption.

The small potential yield, the capital cost of building 5000 km of wave catchers plus generating equipment, and the damage that would be done to all forms of coastal life by such a construction combine to make this a very unattractive energy source.

III TIDAL POWER

Tidal electric power is obtained by using the recurring rise and fall of the sun and especially the moon. The use of tides for power purposes dates back to the tidal mills in Europe during the Middle Ages. Large tides occur when the small high and low tides of the open sea are amplified by relatively shallow bays, inlets, or estuaries. There are a limited number of locations on the earth where the tidal range is great enough to warrant the construction of tidal dam for power production. The largest tidal ranges in the world are: the Bay of Fundy, Canada, 16 m; the Severn Estuary, Great Britain, 14 m; the Rance Estuary, France, 13.5 m; Cook Inlet, Alaska, 10 m; the Gulf of California, Mexico, 9 m; and a number of other locations in Argentina, India, Korea, Australia, and on the northern coast of the U.S.S.R.

Only two tidal power plants have actually been constructed. The Rance location in France has an installed capacity of 240 MW. However, for various reasons this capacity has never all been used. In fact, the effective output is only 62 MW or 540 million kWh/year. Russia completed an experimental plant in 1969 with an output of 400 kW.[16]

Much attention has been paid recently to the great tidal range of the Bay of Fundy, but interprovincial and federal political agreements could not be reached, and Nova Scotia remains as the only province to undertake the project of developing electricity from tidal power. It has developed a pilot project at Annapolis Royal that is to produce 5.7 MW of electricity or about 50 million kWh/year. This energy source will have about 1/10 of the output of the Rance project.

Outside of these few special centres, the possibility of obtaining useful power from the tides appears very remote. Even if it could all be used, it would not make a large contribution in terms of the world energy demand. Häfele considers this source of energy to have minimal importance as an energy option.

The 1974 Survey of Energy Resources for the World Energy Conference suggested a potential total harnessable tidal power of 64 000 MW. At an efficiency of 25% this would yield 16 000 MW, which agrees well with Hubbert's figure of 13 000 MW. This compares to a 1979 Canadian consumption of 316 000 MW.

IV SUMMARY

To put the discussion of the previous pages in perspective, a summary is in order (see Table 9).

Even though 9.7 TWy/y might seem small, it must be remembered that this is a renewable energy supply. To review the non-renewable energy sources the following diagram is constructed:

TABLE 10

Resource	Technical Potential Power in TWy	Depletion Time at 20 TWy/y
Coal	2400	120 y
Oil	400	20 y
Unconventional Oil (tarsands)	400	20 y
Shale Oil	60	3 y
Natural Gas	350	18 y
TOTAL	3610 TWy	180 y

TABLE 9

Estimated Potential of World Renewable Energy Supply

Source Source	Technical Potential Power in TWy/y	Realizable Potential Power in TWy/y	Comments
Biomass	6.0	5.1	Fuel farms require enormous land areas; can be significant in certain locales.
Solar Panels Soil Storage Heat Pumps	5.0	1.0	Solar can be imported locally, but to be effective must go "big" which requires high technology and presently does not seem feasible.
Hydropower	2.9	1.5	A potential to be pursued, but harm to ecology may curtail this method.
Wind	3.0	1.0	Requires much land; must be put into existing electricity grids; could be beneficial locally, e.g. pumping water.
OTEC	1.0	0.5	Ocean environment may be damaged; very expensive to develop on large scale.
Geothermal	2.0	0.6	Best used for comfort and low heat requirements, e.g. greenhouses.
Tides; ocean currents and waves	0.04 0.005	0	Globally insignificant
TOTAL	20	9.7 TWy/y	

The nuclear resource is somewhat more complicated, but the following can be stated: The amount of uranium available world-wide at up to \$130/kg is about 4.8×10^6 tonnes according to INFCE, 1979. Häfele estimates that this figure could conceivably be 24.5×10^6 tonnes (by taking U.S. supplies and assuming uniform distribution world-wide. One hundred and thirty tonnes of uranium are required to produce 1000 MW of electricity for a once-through LWR. To reduce the demand put on the fossil fuels for the production of electricity, Häfele suggests that 10^{13} W of electricity should be produced by uranium by the year 2000. At this rate, the uranium would be depleted by the year 2030. The uranium source could be much extended if other more efficient reactors were to be used. If breeder reactors are used, then the nuclear fuel supply would be essentially infinite.

However, no matter what type of energy-based society is projected, the renewable energy sources can produce approximately 10 TWy/y, and this source should play a prominent part in supplying society with energy for years to come.

From the previous renewable energy supply summary (Table 9) it becomes apparent that there is no one viable source of renewable energy supply to meet the global demand. The biggest source is the forest farms for wood, and intensive agricultural methodology to produce high-yielding carbohydrates that can be converted into fuel carbohydrates, such as is done in Brazil with sugar beets to produce an alcohol-fuel economy, and South Africa extensively engaged in converting corn into diesel fuel. But if maximum land area were to be utilized, it would only produce one-third of global demand projected at a minimum of 16 TWy/y. Note also that the forest and fuel farms supply 50% of the world renewable energy supply. The question must be raised again and again: is it advantageous for agencies (governments) to invest money, time, etc. into highly-questionable reliable sources of renewable energy? Should research and development not be applied to a sure and lasting source of energy? Nuclear energy is one field that will obviously be developed extensively in the next fifty years because it is available, and apart from initial plant construction costs, it is actually cheaper than energy via oil and gas. In fact, a world demand of 16 TWy/y may not be very realistic according to 1980 statistics from B.P.

TABLE 11[17]

Country	Consumption per Capita (10^9J)	Population in 10^6	Total Consumption in 10^{15}J
Canada	391	24	9384
United States	358	220	78760
Netherlands	222	14	3108
Sweden	220	9	1980
West Germany	189	64	12096
U.S.S.R.	180	260	43200
United Kingdom	154	60	9240
France	150	55	8250
Japan	136	115	15640
Italy	107	60	6420
Spain	87	40	3480
China	27	1000	27000
TOTAL		1.9×10^9	2.19×10^{20}J

The total population of the above countries is about 2×10^9, or about one-half of the world's total population. The energy consumed by the above countries was 2×10^{20}J during the year 1979. If we assume that the other half of the world's population consumed half as much energy (i.e. 1×10^{20}J), then the total amount of energy consumed in 1979 was about 3×10^{20}J, an amount equivalent to 10 TW/year. It is unlikely that the world demand will be held to 16 TW/y by the year 2030, which represents an annual growth of less than 1%. A more realistic scenario would suggest a demand of about 25 TW/y fifty years hence, representing an annual growth of approximately 1.8%. Even with this projection, the third world will be unable to reach the energy consumption characteristic of the west. Note that Canada is the greatest demander of energy per capital. This does not necessarily imply that Canadians are wasteful or have achieved an unreasonably high standard of living. Canadians live in a cold climate in which long distances must be covered, and their economy is oriented to the extraction and processing of natural resources which require a large energy expenditure. The U.S.S.R. uses much less energy per capita than Canada. While the climates of the two countries are similar, the standard of living and the percentage of the people engaged in extractive industry are both much lower in the U.S.S.R. than in Canada.

V ELECTRICITY IN ONTARIO

A. Energy Consumption and Electricity Production

The total energy consumption in Canada in 1979 was 10^{19}J of which Ontario consumed 3.4×10^{18}J or about 35%. The energy mix for Ontario and all of Canada are compared in the chart below:[18]

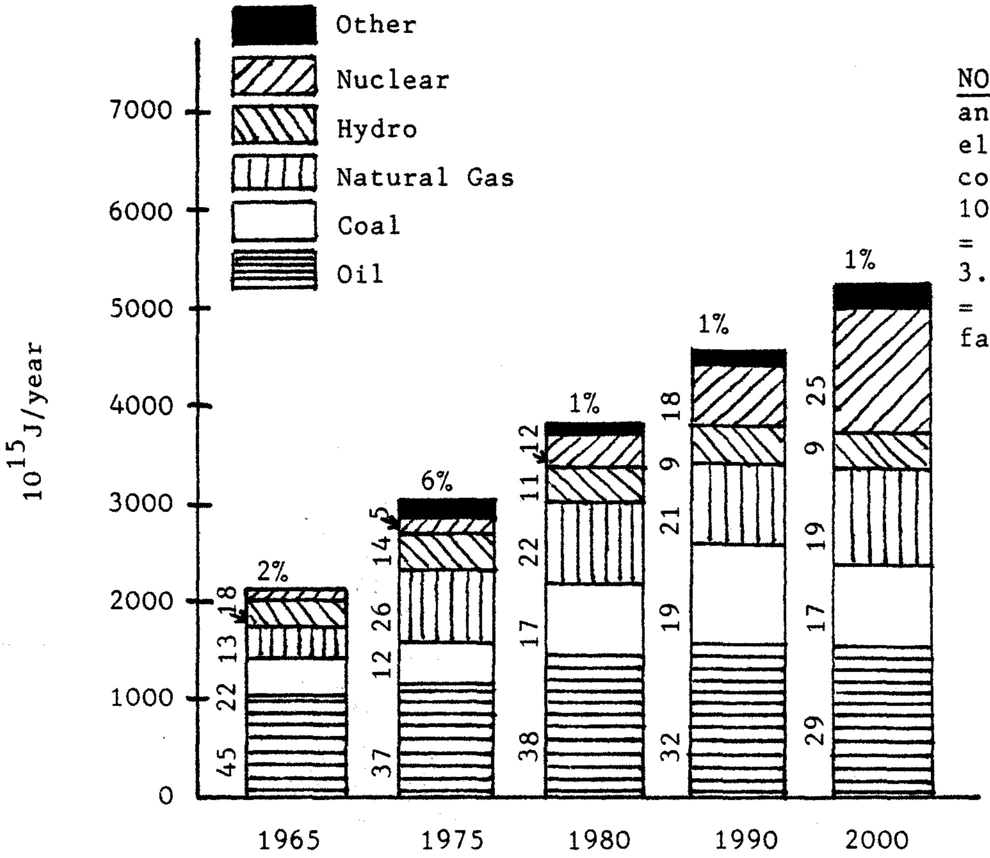
Ontario	Canada
Wood Waste = 1.5%	Wood Waste = 3.3% (B.C. mostly)
Uranium = 10.2%	Uranium = 3.6%
Water Power = 13.0%	Water Power = 23.3%
Coal = 13.8%	Coal = 8.0%
Natural Gas = 21.0%	Natural Gas = 19.0%
Crude Oil = 40.5%	Crude Oil = 42.8%
Electricity consumes 32.7% of primary energy	Electricity consumes 28.7% of primary energy

The 32.7% fraction of the total energy required for the production of electricity in Ontario is distributed as follows: 10.2% from uranium; 13.0% from water power; and 9.5% from coal and oil. Another way of stating it is that 40% of the electricity comes from water power, 29% from coal and oil, and 31% from nuclear power. Small amounts of electricity are bought by Ontario Hydro from neighbouring provinces and the U.S. when it is economical to do so.

The primary energy consumption in Ontario from 1965 and projected to the year 2000 is shown in the following graph:[19]

GRAPH 13

Primary Energy Consumption, 1965-2000



NOTE: Hydraulic and nuclear electricity converted at 10.5×10^{12} J/Wh $= 10.5 \times 10^{12}$ J/ 3.6×10^{12} J = 34% efficiency factor

The projections indicate a decline in the shares of oil and natural gas: oil from 38% to 29% and natural gas from 22% to 19% from 1980 to 2000. The largest increase is seen in nuclear: from 12% in 1980 to 25% in 2000.

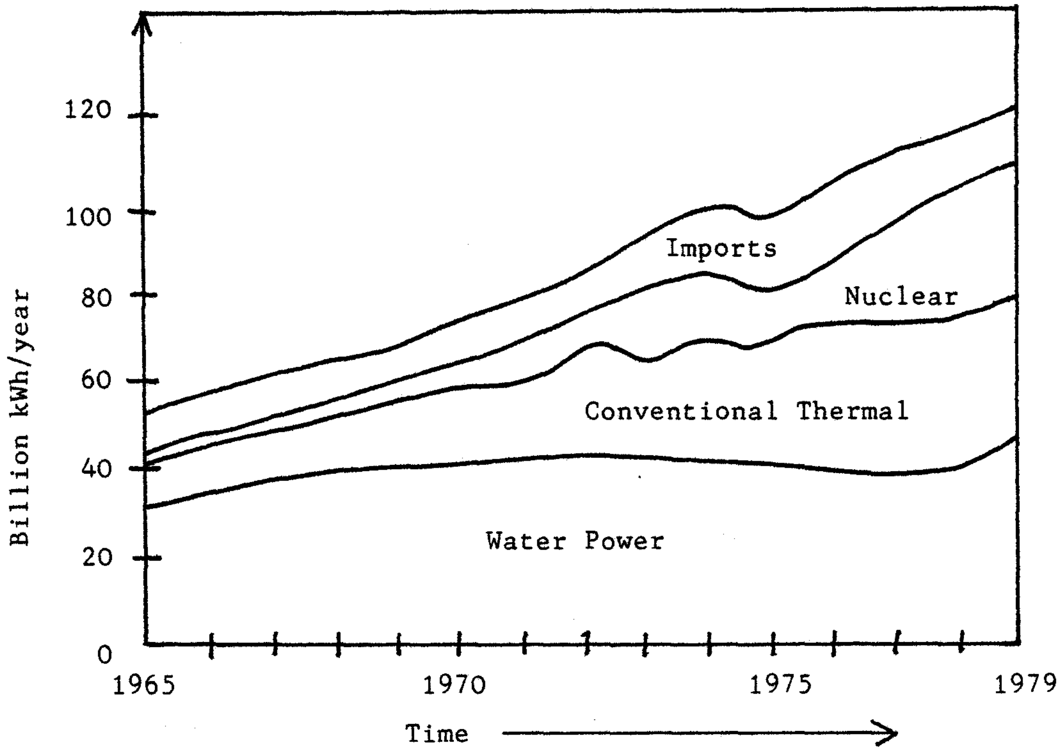
B. Means of Producing Electricity

The origins of Ontario's electricity are presented in the following diagram (Diagram 14).

The almost constant contribution from water power should be noted. However, in 1965 this represented 63% of the total. Up until 1977, most of the increase came from conventional thermal generation (gas, oil, or

DIAGRAM 14

Electricity Supply in Ontario



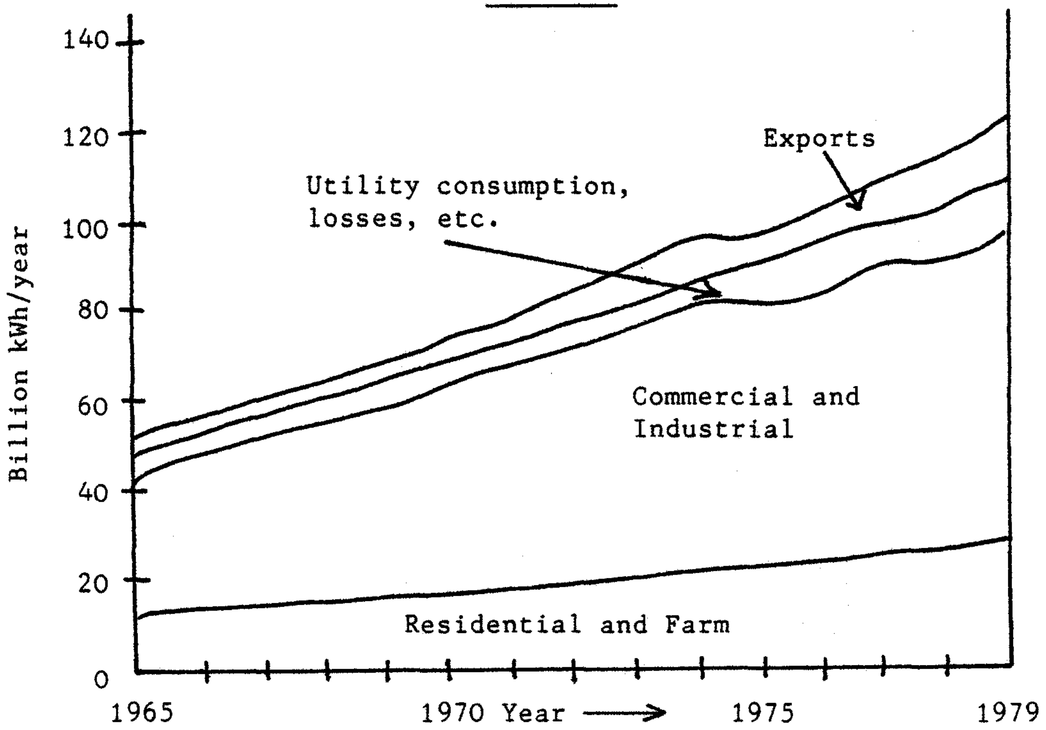
coal) but since 1977, the rising cost of oil has led to the shutdown of all oil-fired thermal plants and the mothballing of some coal plants. The enlarging demands of the future are to be met by an increase in nuclear power.

In 1979 approximately 120 billion kWh of electricity were used, from a primary energy source of 1125 x 10^{15}J. Thus, we have an efficiency of 35-40% (at the source). Ontario Hydro's most recent forecast, in January 1981, predicts an annual increase of 3.1% to the end of this century. In other words, the demand will have doubled at about the year 2000.

C. Electricity Consumption

The consumption of electricity by various sectors in Ontario is shown in the following graph:[20]

GRAPH 14



Certainly electricity consumption could be increased. For example, residential homes could all be heated by electricity, if it is cost competitive. However, if electricity consumption (and production) is to increase, the primary energy base should be shifted from fossil fuels towards other sources such as nuclear energy.

The role played by nuclear power in the generation of electricity is becoming more and more important. Although electricity is not a primary energy source, the fact that energy created in electrical form can be adapted to so many purposes and distributed so readily means that the economics of electrical production is basic to the total energy question. In considering electrical energy production, it is important to realize: (a) that the primary source can be oil, natural gas, coal, wood, hydro, or nuclear; (b) that as fuel costs rise nuclear-based electricity will become preferred over direct fossil fuel heating, despite the losses that occur in going from a primary energy source through steam turbines and electrical generators to electrical power; (c) that the price of electricity is likely to be fairly stable because electrical rates are easily subject to governmental control.

VI NUCLEAR ENERGY

A. Introduction

As stated previously, Ontario Hydro is forecasting that the amount of electricity demand will be doubled by the year 2000. The role of fossil fuels in meeting this demand is decreasing, but nuclear energy is becoming more and more a major source of energy in the form of electricity. To keep in view the global primary supply of energy, Häfele supplies the following figures:

TABLE 12

Two Supply Scenarios, Global Primary Energy: 1975-2030 (TW)

	High Scenario			Low Scenario	
Primary Source	1975	2000	2030	2000	2030
Oil	3.62	5.89	6.83	4.75	5.02
Gas	1.51	3.11	5.97	2.53	3.47
Coal	2.26	4.95	11.98	3.93	6.45
Nuclear 1	0.12	1.70	3.21	1.27	1.89
Nuclear 2	0	0.04	4.88	0.02	3.28
Hydro	0.50	0.83	1.46	0.83	1.46
Solar	0	0.10	0.49	0.09	0.30
Other	0.21	0.22	0.81	0.17	0.52
TOTAL	8	17	36	14	22

Nuclear 1 are all non-breeders, whereas Nuclear 2 includes fast breeder reactors. These two add 8.1 TW or 23% of the total requirement for the high scenario by the year 2030. For the low scenario, the comparable figures are 5.2 and 23%. Häfele feels that the actual demand will be close to the high scenario figure of 17 TW. The demand can only be met with a strong emphasis on nuclear power. Surprisingly, coal is still a very large factor in the supply of primary energy.

B. The Candu System

Canada possesses about 20% of the western world's estimated uranium resources, and can supply a fair amount of the western world's requirements. Federal policy requires enough uranium to be reserved for domestic use to enable each existing and planned Canadian reactor to operate at an average annual capacity of 80% for thirty years from its in-service date. In 1979, Canada produced about 6800 tonnes of uranium, and at a price of $175/kg had an estimated reserve of 415,400 tonnes. Long-term uranium requirements for Ontario's existing and planned reactors amount to about 20% of Canada's total reserve. Ontario consumed 690 tonnes of uranium in 1979, and Ontario Hydro has contracts for a further 91,000 tonnes up to the year 2020.

The Canadian nuclear reactor using natural uranium and heavy water has gained an international reputation for its efficiency and dependability. The Canadian system is not as cheap as the early British system using graphite and uranium, and the American system using enriched uranium and water is only cheap because the enriched uranium had already been prepared as bomb material. If there were no weapon industry and the enriched uranium had to be produced from scratch, the U.S. system would not be viable at all. Over the years the Canadian system has proved itself as the better system. The original difficulties in obtaining heavy water have now been solved. The Pickering nuclear power plant has already saved Ontario billions of dollars in energy costs.

The simplest nuclear fuel cycle is the "once-through" system, and the spent fuel is stored until it is required to be recycled. The recycling has always been part of the strategy of the Candu plan. The

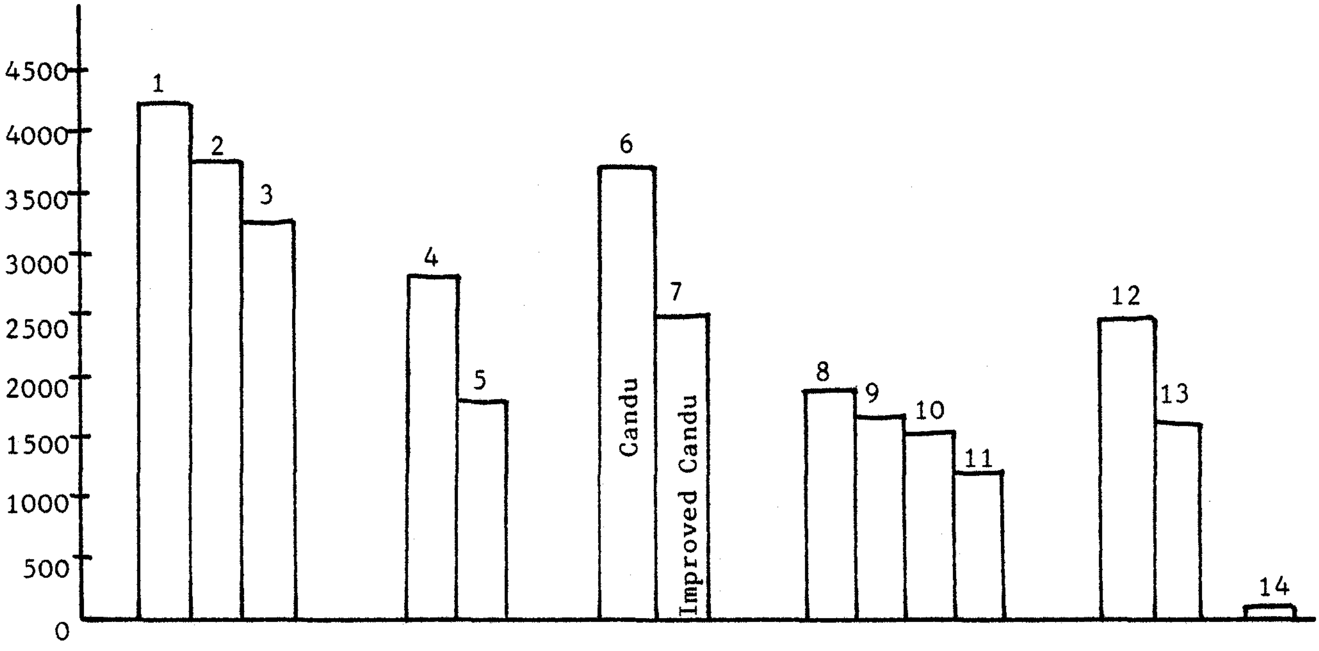
U.S. is taking the fast breeder reactor approach, which is much more complex and which is receiving much criticism. The spent fuel in the Candu system contains a large amount of plutonium which can be extracted and used in place of the ^{235}U which is the active ingredient of new fuel. The Candu system has laid plans to extract the plutonium from the spent fuel and to use it with natural uranium. The third stage of development is to place thorium in the shielding of Candu power reactors (so-called blanket of thorium). This thorium would absorb the neutrons--which are now absorbed in the concrete--to form ^{233}U which is fissile. This process could in fact generate more fissile material in the blanket than the core is consuming, and make further mining of uranium unnecessary. Since the supply of thorium appears to be sufficient for at least a thousand years and probably many times more than this, a Candu thorium cycle can in principle provide energy for so long that it can be classified as a "renewable resource".

The international nuclear fuel cycle evaluation committee met in Vienna in February, 1980 and reported very favourably on the Candu system as a system that is designed to prolong the supply of nuclear fuel, and rated the various systems according to the following chart.

The chart illustrates the uranium required to operate a 1000 MW reactor for 30 years on various fuel cycles, at a capacity of 70%. Each column represents a 30-year period.

1-3 = Light Water Reactor (LWR) Once-Through Fuel Cycle
1 = Reference Cycle
2 = Uranium utilization improved by 15%
3 = Uranium utilization improved by 30%

FIGURE 4



4-5 = Light Water Reactor (LWR) Recycling Uranium and Self-Generated Plutonium
4 = Reference cycle
5 = With improved uranium utilization

6-7 = Heavy Water Reactor (HWR) Once-Through Fuel Cycle
6 = Reference Cycle (natural uranium)
7 = Improved Cycle (low enriched uranium)

8-11 = Heavy Water Reactor (HWR) with Fuel Recycle
8 = Natural Uranium with Recycle of Self-Generated Pu
9 = Thorium with medium enriched uranium (MEU) make-up and denaturing of recycle uranium
10 = Thorium with heavily enriched uranium (HEU) make-up and no denaturing of recycle uranium
11 = Thorium/Plutonium make-up recycle uranium not denatured (for a mix of 1 natural uranium HWR per 2 Th/Pu HWRs).

12-13 = High temperature reactor (HTR) Thorium/Uranium with Recycle
12 = Thorium with HEU make-up and denaturing of recycle uranium
13 = Thorium with HEU make-up and no denaturing of recycle uranium

14 = Fast Breeder Reactor

As the graph indicates, the Candu's lifetime fuel requirements are lower than those of the existing light water reactors in the present "once-through" fuel cycle. With the enhancement afforded by fuel reprocessing, the thorium-U233 advanced HWR cycle could provide the lowest lifetime fuel consumption of any thermal reactor concept.

Anticipated growth in demand for nuclear fuel will probably place some strain on presently-known resources after the year 2000. Enrichment capacity--existing or planned--is sufficient until about 1995 after which some other method must be put into operation. The Candu system can switch to thorium which could greatly reduce the strain on the demand for natural uranium.

C. The Safety of Nuclear Reactors

There is a great public fear about nuclear reactors; a fear that has been enhanced by many vocal and vociferous groups and societies that depict scenarios of utter gloom and destruction. While most of these fears are unfounded, the technology does demand careful controls if harm is not to be done to the environment. Much of the argument about safety is over the question as to whether "man" is competent to exercise these controls over long periods of time. The problem of nuclear safety can be discussed under a number of headings.

1. Reactor Accidents

Many people have the mistaken idea that a nuclear reactor out of control can explode like an atomic bomb. A personal poll of a local high school staff showed that 75% of the teachers asked thought that the Three Mile Island nuclear reactor could have become an atomic bomb if the melt-down had continued. There is a dire need for public education to show that a nuclear reactor is vastly different from an atomic bomb, and that the reactor cannot be transformed into an atomic bomb during a melt-down.

The U.S. Nuclear Regulatory Agency commissioned a study on probabilities of fatal accidents due to man-caused events and it's findings can be summarized as follows:

TABLE 13

Accident Type	Total Number of People Killed	Chance/year of a Person Being Killed
Motor Vehicle	55,791	1 in 4,000
Falls	17,827	1 in 10,000
Fires and Hot Substances	7,451	1 in 25,000
Drownings	6,181	1 in 30,000
Firearms	2,309	1 in 100,000
Air Travel	1,778	1 in 100,000
Falling Objects	1,271	1 in 160,000
Electrocution	1,148	1 in 160,000
Lightning	160	1 in 2,000,000
Tornadoes	91	1 in 2,500,000
Hurricanes	93	1 in 2,500,000
All Accidents	111,992	1 in 1,600
Nuclear Reactor Accidents (100 Plants)	0	1 in 5,000,000,000

We can let these figures and findings speak for themselves, but we must realize that in assessing these figures the probability of death from most of the type of accidents shown is based on actual experience, whereas there never has been a nuclear power plant accident which destroyed life among the general public. There have been industrial accidents within the confines of the nuclear power plant, some of which involved damage by radioactivity. Hence, one is forced to develop a theoretical probability with no experience to test it. While it is generally accepted that the nuclear risks have been consistently overestimated in this calculation, the fact is that they are still estimates. And no one wants an accident that might kill several hudnred people in order to improve the estimate.

The Three Mile Island accident can be somewhat instructive to us in that whatever could go wrong, went wrong and no one died. No fatality occurred in the worst type of nuclear reactor accident possible. To a certain degree, that speaks well of the safety design of the nuclear power plant. The accident also showed that better safety designs and more stringent safety procedures are necessary. These surely will be implemented.

D. Radioactive Emissions from an Operating Reactor Compared with Natural Radiation Levels

There is a general misconception that significant radioactive emissions are a necessary accompaniment to the operation of a nuclear power plant. In fact, the amounts emitted are very small and stringently controlled. The radioactive emissions from a coal-fired power plant are generally much larger because uranium and thorium are present in trace amounts in all coal deposits and some of these elements and their daughters go up the flues into the environment. The Canadian system is under government regulation which demands more stringent controls than the private sector in the United States has done. In the Candu design there is placed a series of impedances between the radioactive core and the perimeter of the power plant to ensure that no one living outside this area will be exposed to more radiation than that allowed by the legal limit. The five impedances which achieve this are:

(1) Radioactive materials embedded in a ceramic structure of fuel pellets.

(2) Fuel pellets encased in zirconium sheaths generally sealed to vacuum technology standards.

(3) The zirconium-sheathed fuel placed within a system of pipes and tubes (the primary heat transport system) constructed to very high-quality standards.

(4) The cooling system housed in a concrete containment structure which is designed and periodically tested to give very low leak rates.

(5) The containment surrounded by about a kilometre of uninhabited area.[21]

The exposure of the general public to radiation from a reactor must be placed in the context of the radiation received from other sources. The natural background radiation to which man is exposed consists mainly of: (i) cosmic rays, (ii) emissions from the disintegration of uranium, thorium, radium and other radioactive elements in the earth's crust, and (iii) emissions from potassium 40, carbon 14, and other radioactive isotopes occurring naturally in the body. At sea level a person would receive from these three sources about 80–100 mrem[22] a year. As the altitude increases, the radiation received from cosmic rays increases at an approximate rate of 2 mrem/150 m increase in altitude. Hence, if a person is to move from Halifax, which is at sea level, to Toronto, at an altitude of about 85 m, the total radiation dose might increase about 1-2 mrem a year. [A mrem is a measure of the biological effect of radiation. Canadian law requires that doses to members of the general public, excluding natural background and medical exposures, do not exceed 500 mrem/year.] However, if one is to move from Halifax to Denver, which is at an altitude of about 5280 feet (1.6 km), the dosage received from cosmic rays would increase by 32 mrem/year.

The largest contribution from man-made sources comes from diagnostic medical X-rays, which adds about the same dosage as the natural background radiation. Other man-made sources are: (i) radioactive minerals present in building materials, phosphate fertilizers, etc., (ii) radiation emitting components of television sets, smoke detectors, etc., (iii) fall-out from atomic weapons, (iv) leakage from nuclear reactors.[23] The above figures can be summarized in the following table:

TABLE 14

Radiation Doses to Average Canadian[24]

Source	Dose (mrem/y)
Natural background (altitude of 150 m)	100
Man-Made Sources	
- Diagnostic X-rays	75
- Other (T.V., etc.)	5
TOTAL	180

This total is increased by about 2 mrem if a person lived continuously at the boundary of the Pickering Power Plant, which is a very small amount compared to the total of 180 mrem/year. Radiation emission from nuclear power plants is minimal compared to other sources of radiation.

E. The Nature of Radioactivity and its Biological Effects

As the atomic number of the elements increases, so does the mass number. For light elements, the maximum stability for a given proton number is achieved when the number of neutrons equals the number of protons. For heaver elements, maximum stability requires that there be more neutrons than protons (e.g., ${}^{208}_{82}Pb$). For atomic numbers greater than 82 (lead), there is no mixture of protons and neutrons which can create a stable nucleus. To obtain stability in these heavier elements, the nucleus undergoes a transformation which essentially replaces protons by neutrons through the emission of alpha or beta particles. Hence, radioactivity is related to the emissions of particles by atoms as they seek more stable states. The type of emission is dependent on the energy parameters of the nucleus. Uranium 238 cannot decay spontaneously by emitting electrons or positrons since this would require energy. However, ^{238}U can emit spontaneously alpha particles and thereby obtain a lower energy state or more stable state.

A nucleus can disintegrate by emitting: (i) an alpha particle, which is a Helium nucleus ($_{2}^{4}He^{2+}$), (ii) a negative electron (beta particle), (iii) a positron, (iv) a neutron, or (v) by undergoing fission in which it splits into two heavy fragments. While in fission there are literally hundreds of ways for the split to occur the most probable ones will involve a light fragment of mass about 94, and a heavy one of mass about 145. In most of these decay processes, the residual nucleus is left in an excited state, and falls back to its ground state by emitting the excess energy in the form of a gamma ray (a short wave-length X-ray).

When discussing the biological effects of radiation on organisms one should distinguish between radiation damage to an individual, and the genetic effects of radiation on the total population.

The injury to cells depends on (i) type of radiation, (ii) the penetrating ability of the radiation, (iii) the portion of the body (tissue) exposed, (iv) the duration of exposure, and (v) the total dose. Alpha, beta, and gamma rays are ionizing particles which lose their energy in passing through matter (cells) by creating positive-negative ion pairs. Because neutrons are uncharged, they cannot produce ionization directly. Instead, neutrons collide with protons or other nuclei in matter and produce recoiling particles which create ion pairs. It takes 30 eV to produce one ion pair, and all radiation possesses much more energy than this amount. The total number of ion pairs is given by the radiation energy in electron volts divided by 30. The manner in which the ionization energy is released along the particle's path also depends on the type of radiation. X-rays and gamma rays produce relatively few ion pairs per millimetre of track. They therefore do not produce concentrated cell damage but scattered damage along the rather long track needed to expend all their energy. They are said to have a low rate of linear energy transfer (LET).[25] The particle radiations (alpha), beta, protons, neutrons) produce perhaps fifty times as many ion pairs per unit distance as do electrons and gamma rays and therefore produce intense ionization over a short range. They thus possess a high rate of linear energy transfer. However, because they lose energy rapidly, they have insufficient energy to penetrate more than a few millimetres of tissue.

Cells, when damaged by radiation, are capable of repair. But if a cell receives an acute dose of radiation, the repair mechanism may be overwhelmed and the cell killed. However, even if the acute dosage is localized, the damage may also remain localized and the destroyed cells replaced by undamaged parts of the body. There are exceptions--bone marrow, the site of red blood cell production, is very sensitive to radiation and damage to bone marrow affects the whole organism since it inhibits the production of red blood cells. However, it is difficult to prove that low levels of radiation exposure are harmful; indeed, there is some pretty good evidence that suggests that low-level radiation may be beneficial. Cellular metabolic repair processes can certainly look after the levels of damage created by the background radiation which man has lived with since the dawn of time. Since people living at high altitudes experience natural radiation levels several times those experienced at sea level without showing a higher incidence of cancer, it is clear that the threshhold for measurable damage is several times the natural background. Where this threshhold is, is a hotly disputed point. The evidence certainly suggests that only a small fraction of all cancers in the general population is due to natural background radiation.

The genetic effect of radiation on an entire population is also a hotly debated issue today, and solid evidence is difficult to come by. A cell which receives a dose of radiation so sufficient to break up many DNA chains, will obviously die and not contribute toward genetic deformities in future generations. But what are the genetic effects of small doses of radiation given over a long period of time on the general population? It seems clear that a gene can mutate only if there are two breaks in the DNA code affecting that genetic quality. This is why high LET radiation which produces spatially-concentrated damage is potentially more dangerous than low LET radiation which creates the same total damage spread over a larger volume of space. Moreover, harmful genetic mutations are generally recessive and tend to be eliminated eventually from the population. It may be possible--but highly improbable--that such mutated genes persist and build up in the gene pool of the population, and that these effects might show up in future generations. Evidence so far indicates this is not to be the case.[26] Chromosomal structure, and hence genetic structure, might be altered by a massive dosage of radiation. But these genetic alterations produce many fetal deaths, and these chromosome mutations would not persist in the gene pool to appear in future generations.

A good case study are the Andes Indians who live at a very high altitude and receive five times the radiation compared to people living at sea level. There is no correlation between the increased radiation and damage to tissues (e.g., cancers). Nor is there an increase in genetically abnormal offspring. Radiation is potentially dangerous and its possible harmful effects must always be considered, but much research is yet to be done to define the relationship between radiation exposure and permanent cell damage and mutated gene transmission.

The general public also has many misconceptions about the term "half-life". It is frequently assumed that the greater the half-life is, the longer people are exposed to this danger of radiation since the radioactive substance will exist for such a long time. But the danger is more closely related to the energy of radiation, and the number of nuclei decaying per unit time per gram of pure radioactive substance--i.e., its specific activity. The specific activity is a function only of the half-life. The shorter the half-life, the higher the specific activity. In other words, the rate of radioactive emission varies inversely as the half-life. Therefore, substances with a very long half-life ($t_{\frac{1}{2}}$), such as U238 which has a half-life of 4.51×10^9 years, emit so few radiations per second per gram that they essentially pose no health or environmental problem. Conversely, the shorter the half-life the more intense the radiation. Radioactive substances (such as Radon 222) with very short half-lives are intensely radioactive, and emit large amounts of radiation per second per gram, and can cause such severe damage to cells that they become irreparable.

Thus to determine the potential danger of a radioactive substance, a detailed knowledge of its decay pattern which specifies the energies of the particles and radiations emitted and their relative probabilities is required. For example, if the substance emits only alpha particles, it poses no danger unless it is ingested into the body or inhaled into the lungs, no matter what the alpha particle energies are. Conversely, unshielded gamma ray-emitting particles can create problems for organisms within several meters of the gamma ray source.

F. Disposal of Radioactive Waste from Nuclear Power Plants

In the fission products formed by nuclear reactors, radioactive forms of nearly all the elements in the periodic table are found. Some of these are highly toxic in their own right. Their radioactivity simply makes them even more toxic. Any attempt to label all fission products as "dangerous" or "highly dangerous" is irresponsible fear-mongering. This is not to negate the dangers of exposure to radioactivity, but it should be realized that much of the "dangerous" radioactivity can be disposed of quite safely. The fission products can be grouped into three categories: (i) those products with a very short half-life, (ii) those with a medium-length half-life, (iii) those with a very long half-life. The total amount of radioactive waste to be disposed of annually is relatively small in volume. The spent fuel from Pickering from 1980 to the year 2000 can all be stored in one pool 35 m x 16 m x 8 m. After ten years of contained storage, the radioactivity decreases to less than one-tenth of one percent of its initial levels. It is in this fashion that those products with a very short half-life can be dealt with--in ten years most of their radioactive decay is completed.

The most dangerous radioactive wastes or substances to deal with are those whose half-lives are long enough (group (ii) above) that we can't wait for this decay to happen and at the same time short enough that the emissions from them are still intense. The half-life of these dangerous substances ranges from about 100 years to 5000 years. The third group has such a long half-life that their radioactivity is quite feeble and really poses no serious threat to mankind. But a graveyard must be found for nuclear waste.

In the Candu operation, most of the radioactivity is in the spent fuel rods. These are stored under water for five years until the radioactivity has decreased to the point where simple air cooling is sufficient. The elements can now be stored in a dry atmosphere within concrete shielding walls for as long as one wishes. For a permanent disposal, the fuel elements can be dissolved and formed into a glass or ceramic matrix in which the radioactive material is an integral component of glass. These glass beads or blocks can then be stored in holes drilled deep in rock formations which have been stable for at least 500 million years.

The ultimate storage sites must be stable for many years since there are isotopes with very long half-lives (e.g., Pu 239 has a 24,400 year half-life). But there is no reason to believe that the rock formation in Northern Ontario will not be stable for the next 10,000 years as they have been for the last 50 million years.

G. Disposal Programmes

There are various methods by which the high-level wastes may be disposed. Essentially, all programmes involve the encasing of the nuclear waste into some very stable matrix (such as a glass-silicon format) and depositing this encasement into a stable geological formation. Much concern has been raised recently about the instability of all geological structures, but surely there is enough geological evidence that indeed some rock formations are stable for a long period of time. The following table lists some programmes that various countries are contemplating to use to dispose of nuclear waste.

TABLE 15

Some High-Level Waste Disposal Programmes[27]

Country	Geological Development	Scale Demonstrations	First Repository
Canada	Rock Plutons	1990	Post-2000
France	Granite, Clay, Salt	1985-90	"
United Kingdom	Granite, Clay	1990's	"
West Germany	Salt	None scheduled	"
Sweden	Granite	"	"
Belgium	Clay	"	"
Italy	Clay	"	"
Netherlands	Salt	"	"
Japan	Granite	"	"
United States	?	"	"

The U.S. underwent the following plans:

1967-72	Project Salt Vault (Lyons, Kansas)
1972-73	Retrievable Surface Storage Facility
1977	Commercial Reprocessing Deferred
1977-78	Spent Unreprocessed Fuel Facility
1978 ?	Away from Reactor Storage
1979	Interagency Review Report
1980	Resulting Presidential Policy
	Focused National Plan

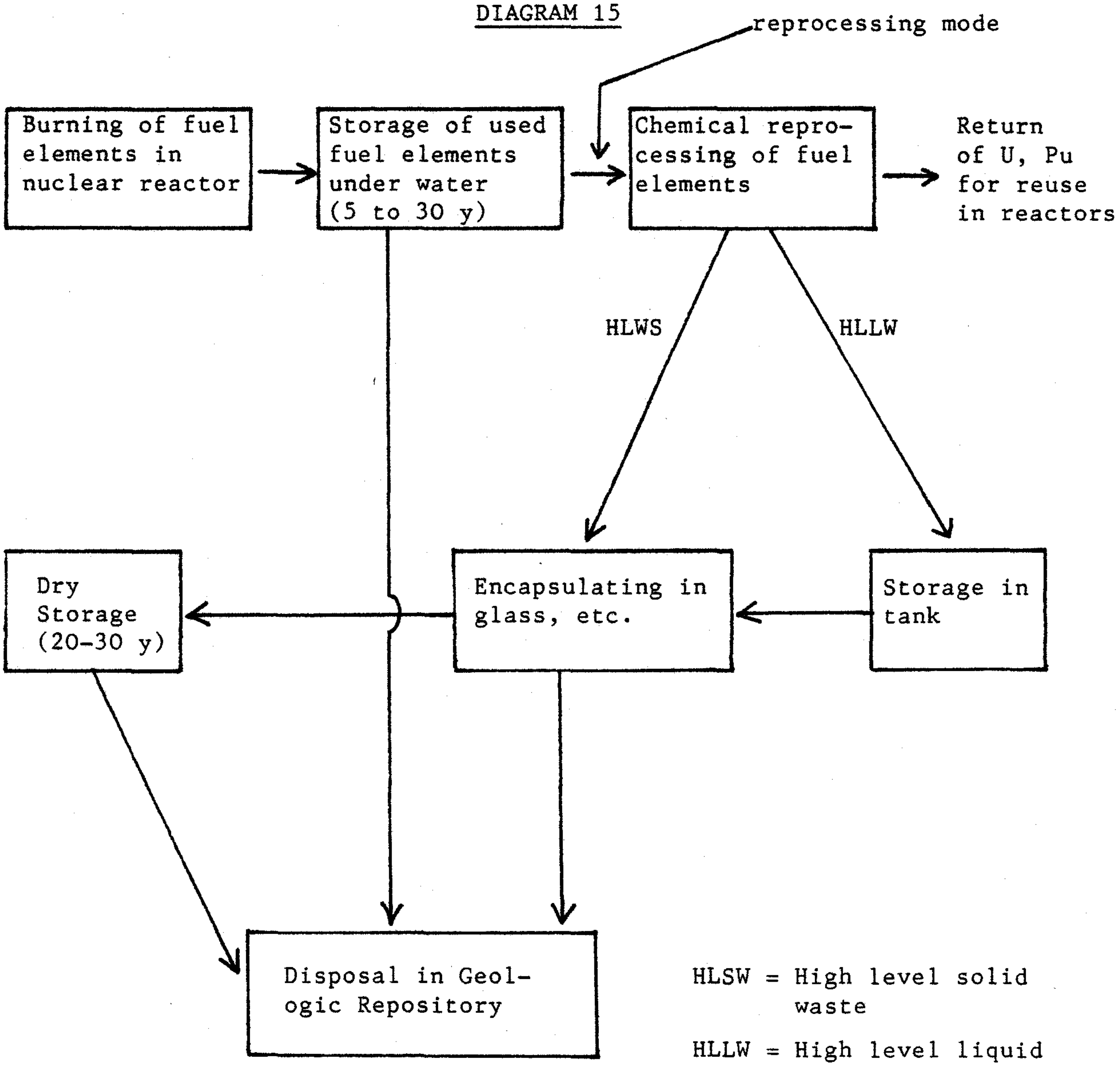
Obviously, politics has become a very definite factor in the determination of the storage system chosen. No plan can secure easy acceptance in the present mood of agitation concerning radioactivity. In retrospect it is unfortunate that some of the waste disposal technology known 30 years ago was not used then to provide a practical demonstration of its effectiveness.

H. Stages in Handling Nuclear Wastes

Not all nuclear power plants operate identically, and not all use the same fuel or moderator, etc. Hence, it is not surprising that there are various methods devised by different agencies to deal with the radioactive material in the intermediate stage--that is between nuclear plant operation and final repository in some geological structure.

A flow diagram depicting the various stages from the utilization of fuel elements in a nuclear reactor to the final storage of waste in a repository is presented below. The storage times quoted are ranges proposed in different national plans.[28]

DIAGRAM 15



HLSW = High level solid waste

HLLW = High level liquid waste

I. Time Scale for Leakage of Wastes to the Biosphere

Sweden has done extensive studies on nuclear waste disposal, and her scientists have determined retention factors for a number of nuclear solid wastes. The time for the radioactive waste to reach the biosphere is given in terms of a retardation factor and the time required for water migration by the relationship: Time to biosphere = Retention factor x Time for water migration. If the time to reach the biosphere is several times the half-life of the substance considered, then so little of the material escapes that there is negligible hazard.

Some retention factors for a number of the major radioactive fission products in granite rock for a reducing environment and slow ground water flow is presented in the table below:

TABLE 16[29]

Element	Retention Factor	Half-life (years)
^{90}Sr	1500	28.1
^{99}Tc	950	2.1×10^5
^{129}I	1	1.7×10^6
^{137}Cs	4 000	30 y
^{135}Cs	4 000	3×10^6
^{154}Eu	200 000	16
^{226}Ra	48 000	1.6×10^3
^{229}Th	80 000	7.3×10^3
^{235}U	23 000	7.1×10^6
^{237}Np	23 000	2.1×10^6
^{239}Pu	5 700	2.4×10^4
^{240}Pu	5 700	6.8×10^3
^{243}Am	610 000	7.7×10^3

Ground Water can move from the repository to a lake or well in

400 to 3,000 years. On this basis, Sr 90 will not escape from the repository in less than 400 x 1500 = 600,000 years. Since this time span is 20,000 half-lives, the amount of Strontium 90 escaping in 400 years is completely negligible (about 10^{-6000}). Similar calculations will show that none of the elements except ^{99}Tc, ^{129}I, ^{135}Cs, ^{235}U, and ^{237}Np would escape in measurable amounts. Since all of these are only feebly radioactive, they pose no problems in the concentrations which would reach the biosphere.

J. Mine Operations and the Environment

Perhaps the greatest danger lies at the very source of nuclear power: the mines that produce the raw materials. Each tonne of ore mined yields 1.0 kilogram of uranium oxide, and one tonne of tailings which contain all daughters of uranium. The Elliot Lake mine produces 7,000 tonnes a day or 2,500,000 tonnes a year, which is a staggering figure. The mining process involves heavy use of sulphuric acid, which creates another hardship on the environment, but this can be neutralized. The iron sulphide present in the tailings (3-4%) can be oxidized by the air and moisture to more sulphuric acid. This must be prevented.

The greatest problem, however, is the radioactive contamination of the environment. Uranium constitutes only 0.1% of the rock structure that is to be mined. Uranium decays naturally and eventually ends up as stable lead (see the following Table 17). But some intermediate elements are very radioactive. Three of the most dangerous ones are thorium 230, radium 226, and radon 222. Thorium 230 has a half-life of 75,000 years, and is the source of radium 226, which has a half life of 1620 years. Radium 226 emits alpha particles which are accumulated in bones and hence very toxic. Radon 222, a decay product of radium 226, with a half-life

TABLE 17[30]

The Uranium Series

Radioelement	Corresponding Element (2)	Symbol	Radiation	Half-Life	Amount Present
Uranium 1	Uranium (92)	^{238}U	α	4.51×10^{9} yr	1000 g
Uranium X_1	Thorium (90)	^{234}Th	β	24.1 days	1.46×10^{-8}
Uranium X_2^*	Protactinium (91)	^{234}Pa	β and I.T.	1.17 min.	4.9×10^{-13}
99.87 % | 0.13%					
Uranium II	Uranium (92)	^{234}U	α	2.48×10^{5} yr	5.5×10^{-2} g
Uranium Z	Protactinium (91)	^{234}Pa	β	6.66 hr	1.7×10^{-10}
Ionium	Thorium (90)+	^{230}Th	α	7.5×10^{4} yr	1.66×10^{-2} g
Radium	Radium (88)+	^{226}Ra	α	1.62×10^{3} yr	3.6×10^{-4} g
Ra Emanation	Radon (86)+	^{222}Rn	α	3.82 days	2.3×10^{9} g
Radium A	Polonium (84)	^{218}Po	α and β	3.05 min	1.4×10^{-12}
99.96% | 0.04%					
Radium B	Lead (82)	^{214}Pb	β	26.8 min	1.2×10^{-11}
Astatine-218	Astatine (85)	^{218}At	α	2 sec	1.4×10^{-14}
Radium C	Bismuth (83)	^{214}Bi	β and α	19.7 min	8.6×10^{-12}
99.96% | 0.04%					
Radium C	Polonium (84)	^{214}Po	α	1.5×10^{-4} sec	1.3×10^{-18}
Radium C"	Thallium (81)	^{210}Tl	β	1.32 min	5.0×10^{-13}
Radium D	Lead (82)	^{210}Pb	β	19.4 yr	3.2×10^{-7}
Radium E	Bismuth (83)	^{210}Bi	β and α	2.6×10^{6} yr	5.4×10^{-1} g
100% | 10^{-5}%					
Radium F	Polonium (84)	^{210}Po	α	138.4 days	8.4×10^{-8}
Thallium-206	Thallium (81)	^{206}Tl	β	4.23 min	2.0×10^{-12}
Radium G (end product)	Lead (82)	^{206}Pb	None	Stable	1000 g

* Undergoes isomeric transition (I.T.) to form uranium Z (^{234}Pa); the latter has a half-life of 6.66 hr, emitting radiation and forming Uranium II ^{234}U.

+ Dangerous

of 3.8 days, is a gas which can be breathed into the lungs, causing extreme damage.

A few words should be said about the amounts of radioactive nuclides present in the tailings. Let us start with one tonne of rock from which 1 kg of uranium is extracted (0.1% concentration). This leaves the daughter nuclei in the tailings. But how much? The whole uranium chain--from ^{238}U to ^{206}Pb is in secular equilibrium--that is, the ratio of the number of nuclei of the daughter present to the number of nuclei of the parent is equal to the ratio of their half-lives (this occurs when the half-life of the parent is much longer than that of the daughter). To determine, for example, the amount of Thorium present, one can write:

$$\frac{N\,T_h^{230}}{Nu^{238}} = \frac{t_{\frac{1}{2}}\,Th^{230}}{t_{\frac{1}{2}}\,U^{238}},$$

$$\frac{\text{Mass of } Th^{230}}{\text{Mass of } U^{238}} = \frac{t_{\frac{1}{2}}\,Th^{230}}{t_{\frac{1}{2}}\,U^{238}} \times \frac{230}{238}$$

$$\therefore \text{ Mass of } Th^{230} = \frac{1000\text{ g} \times 7.5 \times 10^4\text{ yr}}{4.51 \times 10^9\text{ yr}} \times \frac{230}{238}$$

$$= 1.66 \times 10^{-2}\text{ g}$$

which is a very small amount compared to the 1000 g of ^{238}U extracted. Hence, those daughter nuclei of very short half-life would be present in very low concentrations in the tailings. The amounts present with one kilogram of uranium is indicated in the previous chart.

The natural radioactivity of uranium in unmined rock is not particularly dangerous because: (i) it has an extremely long half-life, (ii) it is of very low concentration (0.1%) and (iii) it is contained within the original mineral or rock structure, within which also the decay products are retained. But mining destroys this matrix of rock structure and concentrates the intermediate products in slurry form in tailing dams or ponds. Hence, there can be a build-up of Thorium, which is a major problem. Bismuth is present in greater quantities, but it is regarded as relatively harmless.

Another problem that arises is that the liquid in the tailing ponds will drain off, carrying along with it water soluble radium salts. The liquid wastes contain significant amounts of radium which can be removed by a precipitation process, but much radium and other radionuclides are bound to the solids. These nuclides can dissolve and be carried off by the various streams and rivers and pollute the environment a considerable distance from the uranium mine. These radionuclides must be removed either by containment or by removal by chemical means leaving the solid wastes radioactive-free.

McMaster University is presently studying various techniques to remove the radium by chemical means. The results look promising, and it seems that probably 90% of the radioactive substances can be removed successfully from the solid waste.

K. Transportation

The public outcry against the trnasportation of uranium oxide "yellow cake" through residential areas is heard frequently. However, this yellow cake is relatively harmless. A truck transporting gasoline is a much more potential danger.

As reprocessing of fuel becomes more important, the transportation of plutonium does become an issue. The security is minimal during the transportation, and theft and leakage could easily occur under current conditions.

L. Political

The ultimate danger of a nuclear reactor is that it be used to produce plutonium for the production of nuclear bombs. Even though all nuclear plants are to be open to inspections by the International Atomic Energy Agency, it is a very difficult matter to have such an accurate bookkeeping that will account for every gram of plutonium 239 or uranium 235. Nuclear reactors run at high power to produce electricity, and at high power the plutonium produced is a mixture of fissionable plutonium and other non-fissionable plutonium isotopes. The resulting plutonium is not bomb material. However, it is possible to run a nuclear reactor at low power and produce pure weapons' grade plutonium. In reaction form:

$$\begin{tikzcd}
{}^{238}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \arrow[r] & {}^{239}_{92}\mathrm{U} \arrow[r, "\text{preferred if few neutrons available--}", "\text{i.e., low power}"'] \arrow[d, "+\ {}^{1}_{0}\mathrm{n}"', "\text{preferred if many neutrons available, i.e. high power}"] & \beta\text{ decay } {}^{239}\mathrm{Pu}\text{ which is fissionable} \\
& {}^{240}_{92}\mathrm{U} \arrow[d, "\beta\text{ decay}"] & \\
& {}^{240}_{94}\mathrm{Pu}\text{ which is non-fissionable} &
\end{tikzcd}$$

Ironically, the NRX research reactor which Canada gave to India was an ideal instrument for producing bomb-grade plutonium, and India used it to produce its first bomb despite its solemn promise to Canada not to do so. Candu reactors are not attractive for making weapon-grade plutonium.[31] The nuclear weaponry proliferation is a grave problem, and there is no solution yet. The recent military action in the Mid-East and Europe should make us shudder. Man has become a technological god rather than a compassionate creature.

M. Heat

The water coolant in any electrical power plant whether powered by fossil fuel or uranium is returned to its source at a higher temperature than its original temperature. When a lake or river is used as a source of cooling water, the increases in temperature caused by rejected coolant alters the ecological climate of the source. Thus Lake Huron from Southampton to Goderich has experienced an increase in temperature created by the nuclear power plant at Douglas Point. In England, where there are no large bodies of fresh water, the rejected coolant is cooled in large cooling towers. These can create serious fog conditions for some miles downwind.

The low-grade heat rejected by both coal- and nuclear-fired electrical power plants is a large resource that has up to now been wasted. The low grade heat from Douglas Point could be used to maintain greenhouses that would enable Canadians to have home-grown vegetables at economical prices. Such large area use of this low-grade heat will certainly develop (a small pilot plant is already in operation at Douglas Point) as fossil fuels increase heating and transportation costs.

All sources of power create hazards. The air pollution caused by automobile, industry, coal power stations, etc., is a very serious problem. The climatic changes caused by air and thermal pollution by the non-nuclear power sources are much greater than the nuclear pollution. If an effective control of U^{235} and Pu^{239} production can be brought about, then nuclear power is certainly a very desirable alternative energy source. For many, however, this is a very big "if".

N. Nuclear Farm

S.J. Amir in Energy Communications 5(5) 359-365 (1979) is so convinced of nuclear power that he proposes a system of 12 or 16 "nuclear farms" across the U.S. to supply electrical energy. Each nuclear farm is a complex of 8-12 nuclear reactors built underground and located at least 25 miles from population centers in an area with limited or no public access. He further proposes to have nuclear farms that become waste disposal areas after the plant's lifetime. Each farm would have a radius of about 10 kilometers and each plant in the farm should produce 1000 - 1200 MW of electrical power.

VII COAL

A. Supply

Coal is by far the most plentiful of the earth's fossil fuels. The U.N. statistical Year Book 1972 gives the following figures:

Country	Reserves of Coal	Tonnes x 10^9 Reserves of Lignite	Total
U.S.S.R.	4121	1406	5527
U.S.A.	1100	406	1506
China	1011	-	1011
West Germany	70	62	132
Australia	16	96	112
India	106	2	108
Canada	61	24	85
South Africa	72	-	72
Poland	46	15	61
East Germany	-	30	30
Yugoslavia	-	27	27
Czechoslovakia	12	10	22
Japan	19	2	21
U.K.	15	-	15
Colombia	13	-	13
Brazil	11	-	11
WORLD TOTAL	6641	2041	8682

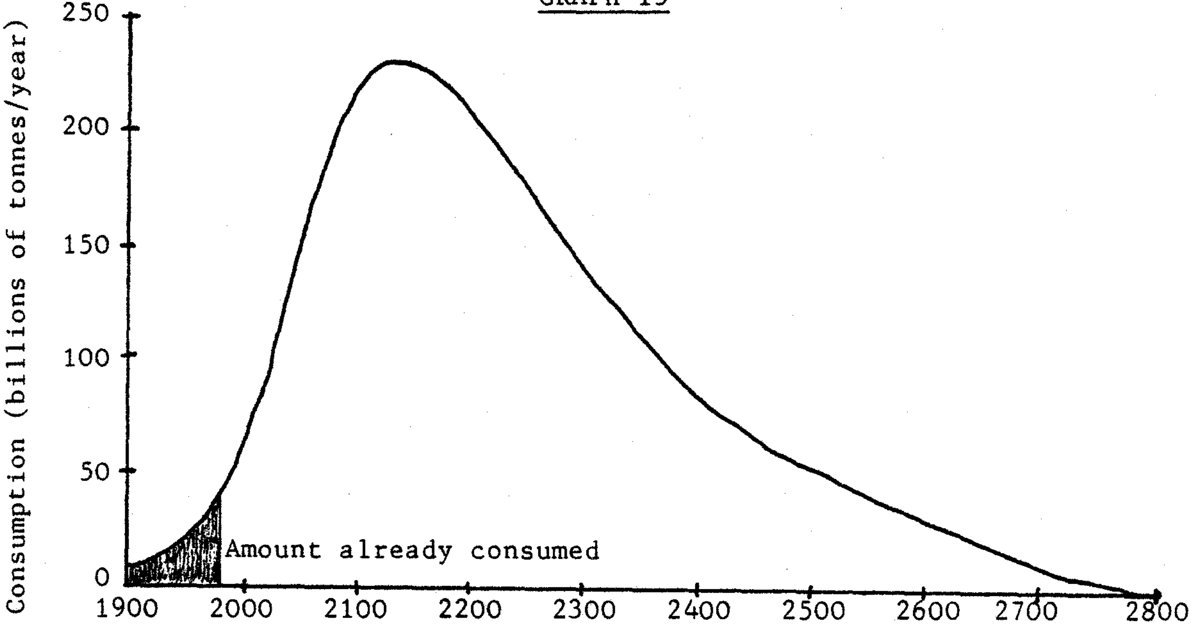
As can be seen, Russia has at least 2/3 of the world's supply.

Coal mining has steadily increased over the years, confounding those who feel that coal mining is a dying industry. The U.N. Statistical Year Books give the following figures:

	Tonnes x 10^6		
Date	Coal	Lignite	Total
1932	870	164	1034
1937	1154	233	1387
1942	1291	314	1605
1947	1204	237	1441
1952	1500	435	1935
1957	1735	593	2328
1962	1857	684	2541
1967	1949	722	2671
1971	2124	805	2929
1972	2145	806	2951

If consumption remains at 3 x 10^9 tonnes/year, the world's supply of coal would be exhausted by the year 2500 (see Graph 15 below). Seemingly, there is plenty of coal to meet the global energy requirements for at least the next 300 eyars.

GRAPH 15[32]



B. Problems

But there are problems. Coal mining is a hazardous occupation. Strip mining wrecks the environment. Coal deposits are not uniformly dispersed over the earth, nor are the deposits frequently near the locale where it is required. Hence, the transportation of coal is itself a problem. The burning of coal also presents great hazard to the quality of air that we breathe. However, modern technology has solved a few problems. The mining operation is becoming less hazardous, and mining companies are required by law to protect the environment. Experiments are also done to transport coal via pipelines in the form of small coal particles suspended in water, called coal slurry.

C. Gassification

But the greatest emphasis today is on coal gassification, which requires a large increase in the net hydrogen/carbon ratio. One source for the necessary hydrogen is water. The ideal reaction would be coal + water $\longrightarrow CH_4 + CO_2$, but this reaction cannot be carried out in a single step, and indirect, sequential reactions are used. Coal is first heated with oxygen and steam-producing hydrogen and carbon monoxide. Some of the CO is heated with steam to produce more hydrogen and CO_2. The hydrogen and remaining carbon monoxide--in proper proportion--react over a catalyst to produce water and methane which can be used in place of natural gas.

D. Liquefaction

Coal liquefaction is also becoming more and more prominent. There are three basic methods by which coal can be converted to synthetic crude oil:

(i) pyrolysis;

(ii) Fischer-Tropsch Synthesis, or indirect hydrogenation;

(iii) direct hydrogenation.

The South Africans selected a Fischer-Tropsch technology for their liquefaction plants. The direct hydrogenation process requires high pressure operations and is more risky than the indirect method. South Africa expects to produce half of its fuel requirements by liquefaction of coal by 1983. The U.S. is planning 2 million barrels/day by 1992 by the process of liquefaction. It is doubtful if this goal will be met. In July, 1980, a 1.5 billion dollar gassification plant was started in North Dakota that is to deliver 137.5 million cubic feet of pipeline-quality gas by the mid-1980's.

The Canadian government is also considering the option of manufacturing gasoline by coal liquefaction. The Department of Energy, Mines and Resources foresees mine-mouth coal liquefaction plants in Western Canada, where most of Canada's coal is located, and where natural gas can be used as the conversion fuel, and the carbon dioxide byproduct could be used in heavy oil recovery. A pilot plant has not yet been constructed in Canada, but West Germany and Japan are presently commercializing liquefaction technology.

VIII SHALE OIL

The greatest deposits are found in Colorado, Utah, and Wyoming. There is a vast amount of oil in shale, but it is very difficult to extract. There is at least a reserve of 200 billion barrels of oil, but extraction methods so far do not make oil shales a feasible alternative.

Some idea of the energy costs invovled in the extraction process can be obtained from the figures in the following proposed pilot project.

The project would consume 76,300 tons of shale containing 34 gallons of oil per ton, and return 50,000 barrels of oil per day. Hence, the input is 76,300 x 34 = 2.6×10^6 gallons of oil. The output would be 50,000 x 42 = 2.1×10^6 gallons of oil. This means that about one-fifth of the 34 gallons (one ton for seven gallons) is required to heat the shale. Upgrading and refining will require additional energy input. It thus appears that the operation is no longer feasible (apart from environmental considerations) when shale has a content of less than about ten gallons of oil per ton of shale. But oil shales containing 5-10 gallons/ton account for about 90% of the shale deposits. Thus only about 10% of the shale deposits could be mined to give an energy profit. This figure would be reduced further if environmental concerns such as landscape destruction, waste disposal, and air pollution are taken into consideration. At best 5-10% of the shale oil deposits could be developed. At an estimated reserve of 200 billion barrels, a net return of a maximum of 20 billion barrels of oil seems realistic. This figure is not large compared to other reserves, and shale oil probably will not be a prominent factor in world energy supplies. (See page 81.)

IX TAR SANDS

The tar sands in Alberta cover an area of 34,000 km^2. The only other notable tar sand deposit is in Venezuela covering 2,300 km^2.

The average thickness of the Alberta sands is 40-80 m, and it is only heavy oils that are found in the sands. The amount of material to be strip-mined is staggering—two tonnes of material produce 1 barrel of oil. An output presently of 20,000 barrels/day yields 20,000 tonnes of waste that must be placed somewhere. Canada today requires about 2,000,000 barrels of oil/day so that a production of 20,000 barrels/day is a small amount. But there are 65 billion barrels[33] that can be recovered, which is about 20% of the total Mid-East reserves. If the deeper deposits are ever mined, and a given 30% recovery factor could be devised, then another 230 billion barrels of oil could be obtained. Hence, the ultimate recoverable oil from the tar sands (including the 65 billion barrels) is about the same as the total Mid-East reserve. There are two major drawbacks to the Alberta tar sands: (i) environment, (ii) technology. As the cost of Mid-East oil continues to increase, the tar sands will become more and more viable for complete development.

X FUSION

The ultimate aim of nuclear energy and technology has always been fusion rather than fission. Almost fifty years of research has been spent on trying to produce a controlled fusion reaction without success. Uncontrolled fusion is accomplished readily enough in the hydrogen bomb.

A temperature of about 100 million degrees Celsius is required to sustain a fusion reaction. The temperature is obtainable, but the confinement of the plasma (nuclei stripped off their electrons) is the problem since all materials are vaporized at that temperature. Two methods are presently used to confine the plasma: (i) by magnetic fields: since the electrically-charged particles can be readily manipulated by strong magnetic fields, it is in principle possible to keep a plasma isolated from the container walls by suspending it within a closed magnetic field—a so-called magnetic bottle.

However, the trouble with all magnetic bottles is that they leak. There always is a junction between the magnetic field and electrical input where leakage occurs. The heat flowing out through the leak invariably destroys the container.

(ii) The inertial confinement technique, whereby a small droplet of hydrogen fuel is placed in the center of a large spherical chamber and is then hit with an extremely powerful laser. The sudden burst of energy compresses the droplet to such an extent that the temperature rises to the point where the hydrogen nuclei are "fused". Up to this date, the droplets have always been scattered rather than compressed and fusion has not occurred.

The sun's energy is produced by the process of fusion. At the twenty million degree temperatures and high pressure in the sun's interior, nuclear velocities and densities are very high. The high velocities result in the close nuclear collisions required for fusion and the high densities create high probabilities of such close collisions occurring. The force of gravity also supplies a confinement "bottle" which does not leak. This "bottle" is of dimensions comparable to the sun's millions of times greater than the "bottles" man attempts to build in the laboratory.

There are two different nuclear processes which are of prime importance for energy production in the sun and other stars:

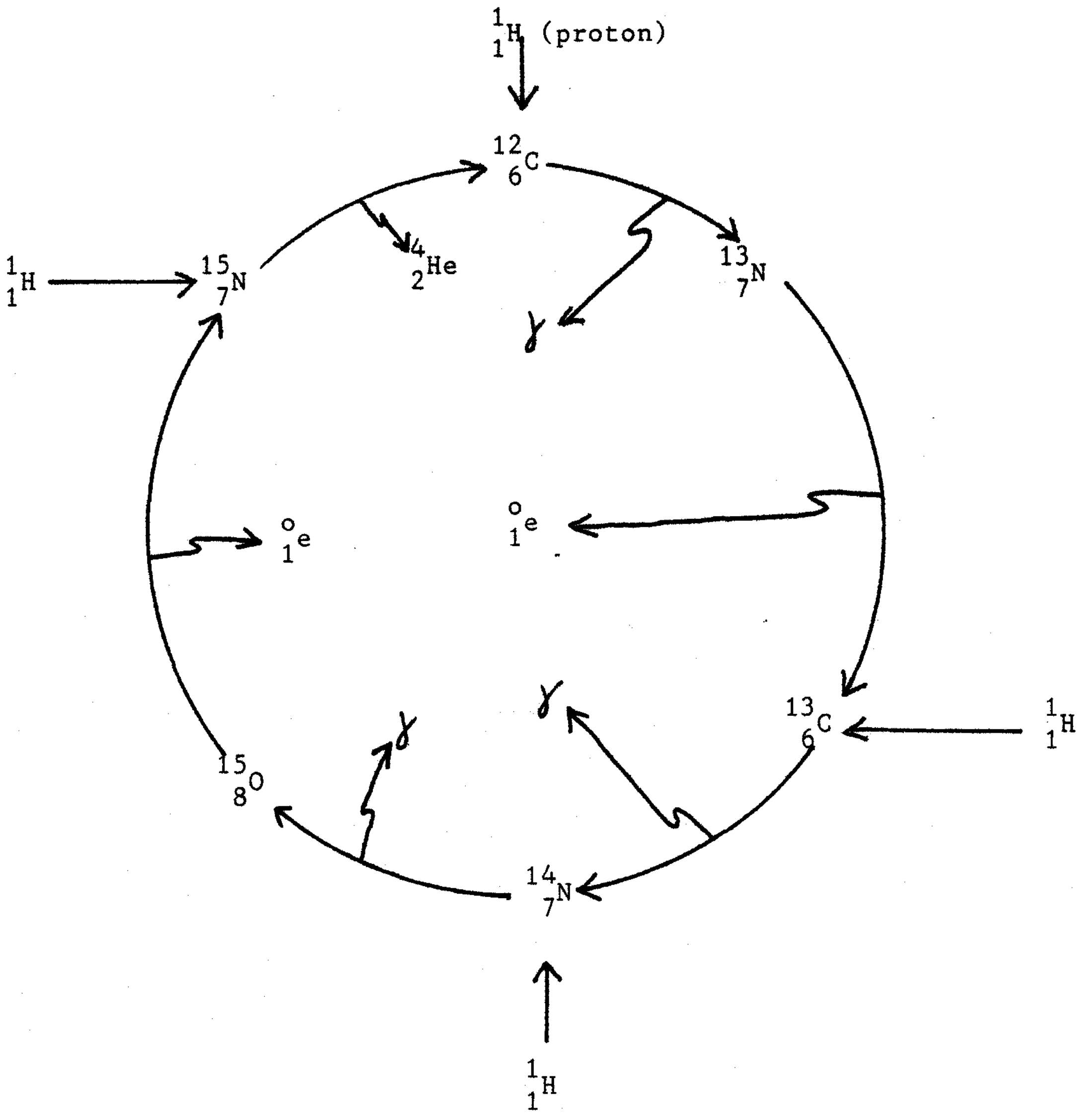
(a) In the H-H reactions, two protons collide to form a deuteron with the emission of a position:

$$ {}^{1}_{1}H + {}^{1}_{1}H \longrightarrow {}^{2}_{1}H + {}^{o}_{1}e + \text{energy } (\gamma \text{ rays}). $$

(b) In the carbon cycle, first proposed by Bethe, the carbon nucleus absorbs four protons and emits them in the form of an alpha particle or helium ion. The carbon cycle is the dominant one in all stars brighter than the sun. It proceeds at temperatures of about

20×10^6K. The essential steps in the carbon cycle are illustrated in the figure below.

FIGURE 5



To obtain a sufficiently high density in the laboratory, and to reduce the temperature, deuterium is used rather than hydrogen. This reaction can proceed at a lower temperature of about 1×10^6K.

$^2_1H + ^2_1H \longrightarrow ^4_2He + \gamma.$

At Princeton, N.J., U.S.A., a temperature of 75 million degrees Celsius has been reached in a magnetic bottle called the TOKAMAK. A larger unit called the Tokamak Fusion Test Reactor is being built to be ready in 1982, which is to increase the temperature to at least 100 million degrees Celsius.

In Livermore, California, scientists are working on the inertial confinement approach. Tiny droplets of deuterium-tritium are confined in small glass beads, and hit with an extremely powerful laser, that has an output of 30 trillion watts. However, no sustained reaction has been obtained. Presently, a more powerful laser (called the NOVA) is being built that will have an output of 300 trillion watts of power.

Japan, West Germany, Russia and the U.S.A. are spending large amounts of money on the fusion process. The National Research Council and Canadian scientific community decided a few years ago that Canada did not have either the financial or human resources to do "world class" fusion research. At this time it was decided to carry on a minimal programme which would develop a cadre of Canadian scientists capable of entering the field quickly if controlled fusion became an energy possibility.

Fusion is very attractive in that its energy output is ten times greater than the fission process, and the source of raw materials (fuel) is probably limitless. This is not so for the deuterium reaction since the Lithium required in producing the deuterium is in short supply.

In one litre of water there is as much energy as there is in about 2,500,000 litres of gasoline. Undoubtedly, we are still decades away from obtaining this goal, but the pace is accelerating, and a scientific break may even be accomplished soon in the laboratory.

When that occurs, the world will finally have a sure and permanent source of energy.

NOTES - CHAPTER TWO

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3. See for example Weekend Magazine, September 27, 1980.

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17. B.P., Statistical Review of the World Oil Industry, 1979, p. 27.

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21. S. Banerjee, "The Safety of Nuclear Power Stations", Engineering Journal, July 1978.

22. *Ibid*.

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24. *Ibid*.

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27. J. Haley, *Nuclear Waste Management--An Overview*, Westinghouse Publication, 1979.

28. *Science Teacher*, February 1981, p. 25.

29. *Ibid*., p. 27.

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31. Pakistan has a Canadian Candu reactor; a fact that has been used by the anti-nuclear lobby to claim that Pakistan is building nuclear weapons. Those in a position to know say there is no evidence for this claim.

32. M.K. Hubbert, *Resources and Man*, San Francisco: W.H. Freeman, 1969, p. 101.

33. *Almanac of Canada 1981*, Don Mills, Ont: Corpus Publishers, 1981, p. 178.

CHAPTER THREE

HEAT PUMPS

I BASIC DESIGN AND OPERATION

The heat pump can be defined as a device that moves heat from a low temperature region to a region of high temperature. The residential air-to-air heat pump, the most common type in use today, extracts heat from low temperature outside air and delivers this heat to the high temperature air indoors. To achieve this, work is done on the working fluid (a refrigerant) of the heat pump.

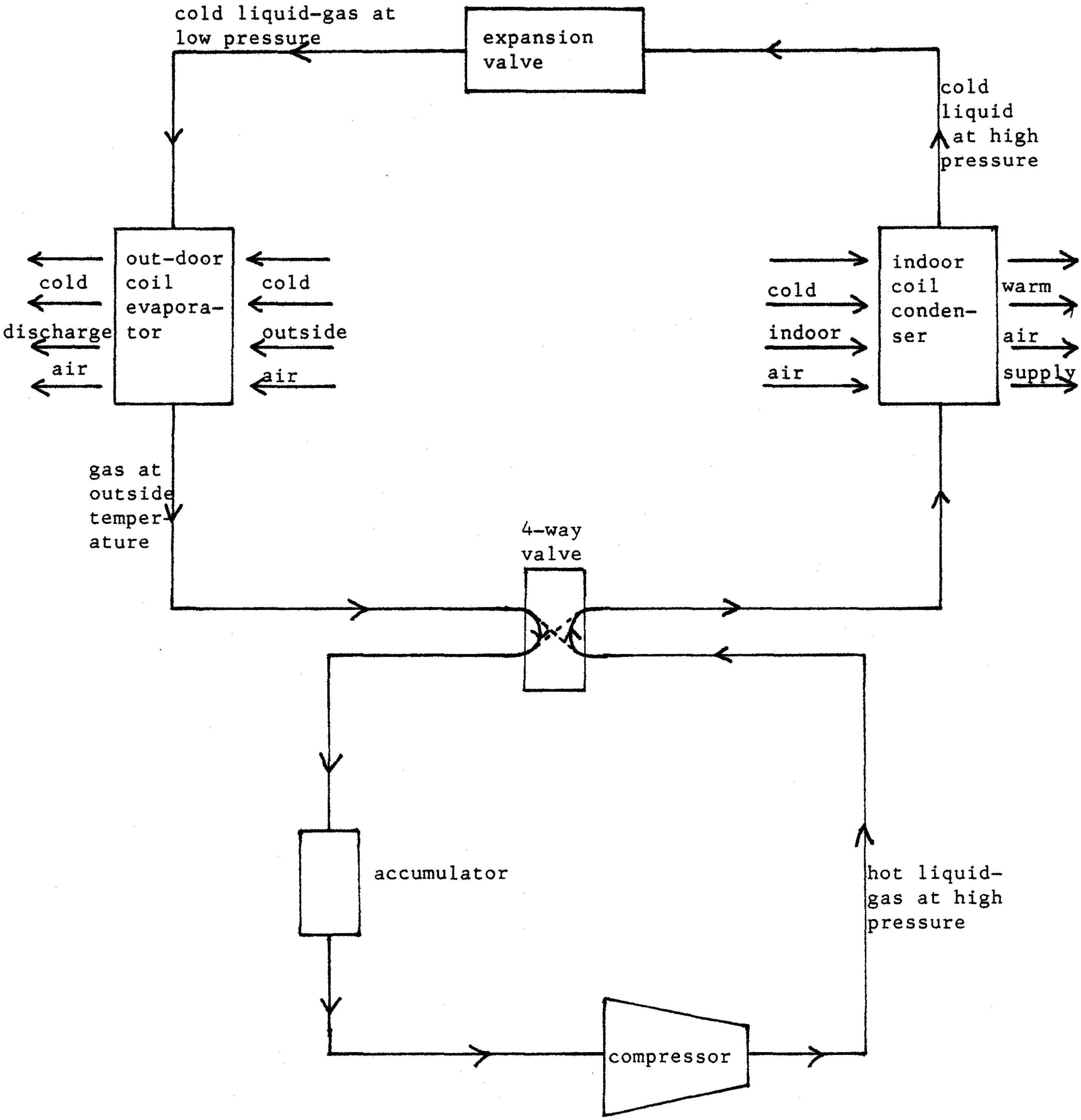
Historically, heat pumps have been designed and sold as an economical method of cooling a building in the summertime and heating that building during the winter. Most commercial heat pumps on the market today still serve this dual function. However, the recent rapid increase in the cost of energy has brought about a renewed interest in heat pumps that are specifically designed for the heating function only.

The heat pump in Diagram 16 (on the next page) can be used as a refrigerator (air conditioning) by switching the four-way valve to reverse the direction of flow of the working fluid, as shown by the dashed lines in the valve. For summer cooling, the condenser should ideally be placed outdoors, and the evaporator indoors; for winter heating, the condenser should be indoors and the evaporator outdoors--the condition which the Ontario climate demands.

The heat pump in Diagram 16 accomplishes space heating by transferring heat from the low temperature air outside to the lower temperature fluid which is evaporated in the outdoor heat exchanger and becomes

DIAGRAM 16[1]

Heat Pump Schematic in the Heating Mode



the cool vapour or gas. Work is done by the compressor on this cool gas which becomes compressed with a resultant increase in temperature. The gas is superheated when it leaves the compressor since it is above its saturation temperature for its pressure. This temperature is now higher than the inside air temperature and heat is removed from it by the indoor heat exchanger or condenser, and the gas is condensed. The heat of condensation and the heat of cooling both warm the inside air. The cooler liquid now moves through an expansion valve which reduces the pressure. The gas-liquid mixture is cooled by the expansion to a temperature below that of the outside air and moves through a heat exchanger (evaporator) in which it is warmed to that temperature. This warmed gas is now compressed and the cycle repeats itself. The liquid accumulator eliminates the possibility of liquid return to the compressor. In some designs the liquid refrigerant is passed through a heat exchanger coil, located at the bottom of the accumulator. This allows the main evaporator to be operated in a flooded condition, with a subsequent improvement in internal heat transfer. The whole cycle can be summarized in the following simple diagram (Diagram 17).

State 1 = refrigerant gas at low pressure and temperature T_L

State 2 = superheated refrigerant gas at high pressure and temperature above T_H

State 3 = cooled refrigerant liquid at high pressure and temperature T_H

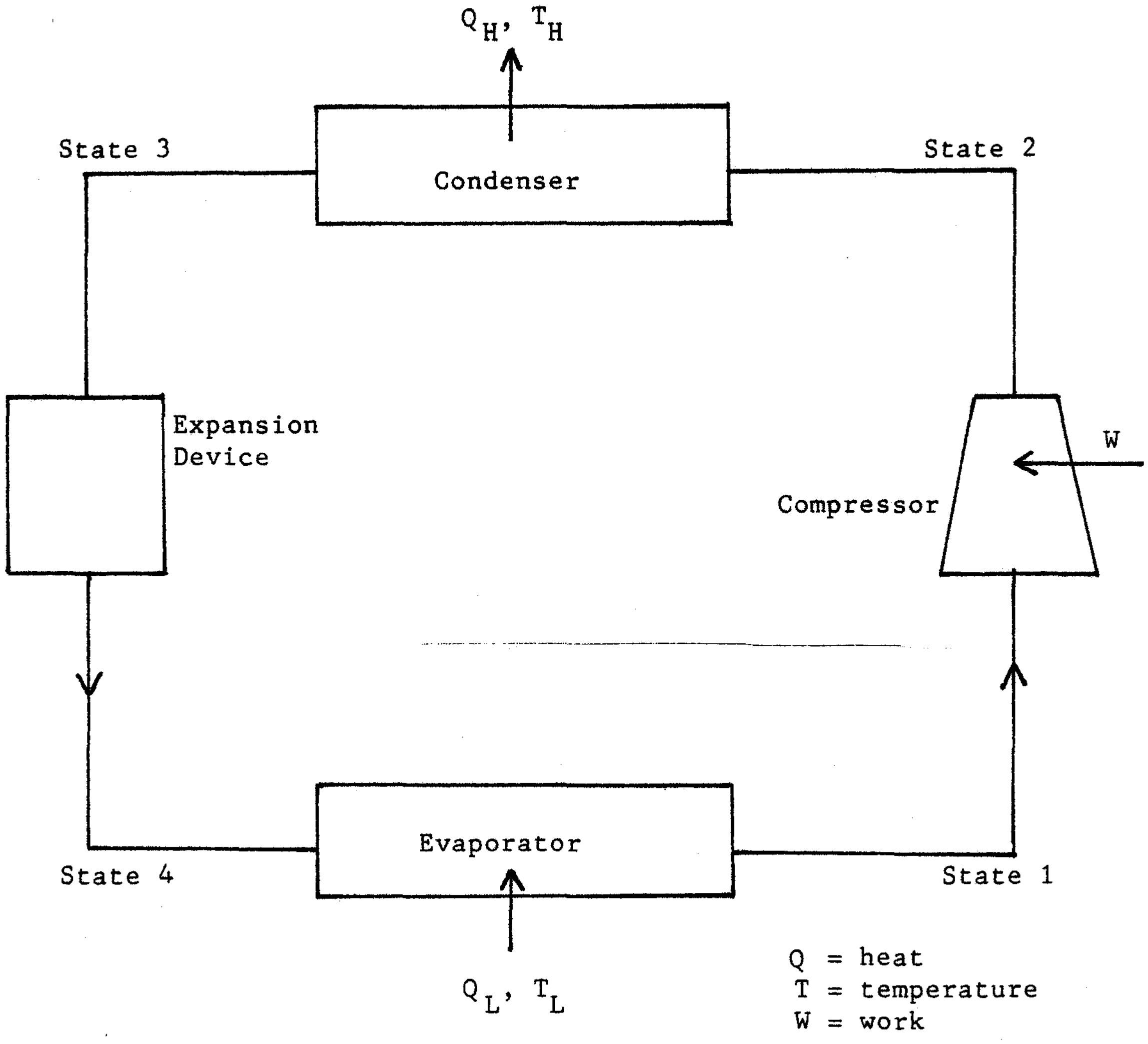
State 4 = cooled refrigerant liquid-gas at low pressure and temperature below T_L

II THE CARNOT CYCLE

The French engineer, Sadi Carnot, in 1824 applied thermodynamics to a study of the ideal heat engine. The so-called Carnot cycle is of

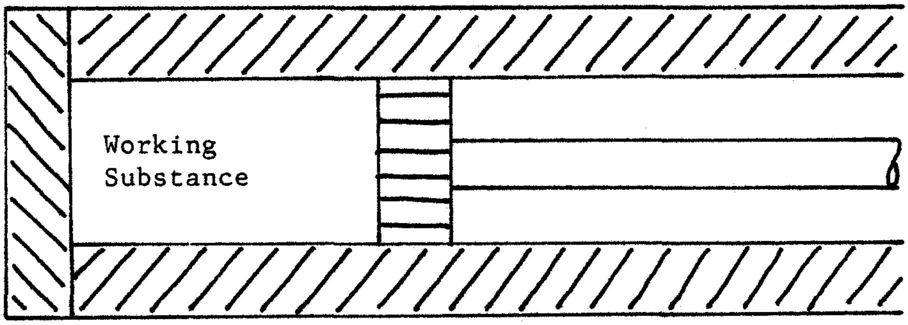
DIAGRAM 17[2]

Basic Heat Pump Components



fundamental importance because it supplies a theoretical limit to the efficiency that a real heat engine can have, and this cycle is the standard against which the performance of all practical heat engines is measured.

In the Carnot engine shown schematically below,[3] the working substance--usually a gas, and referred to as a gas in this discussion--is contained in a cylinder. Suppose that the insulation at the closed end



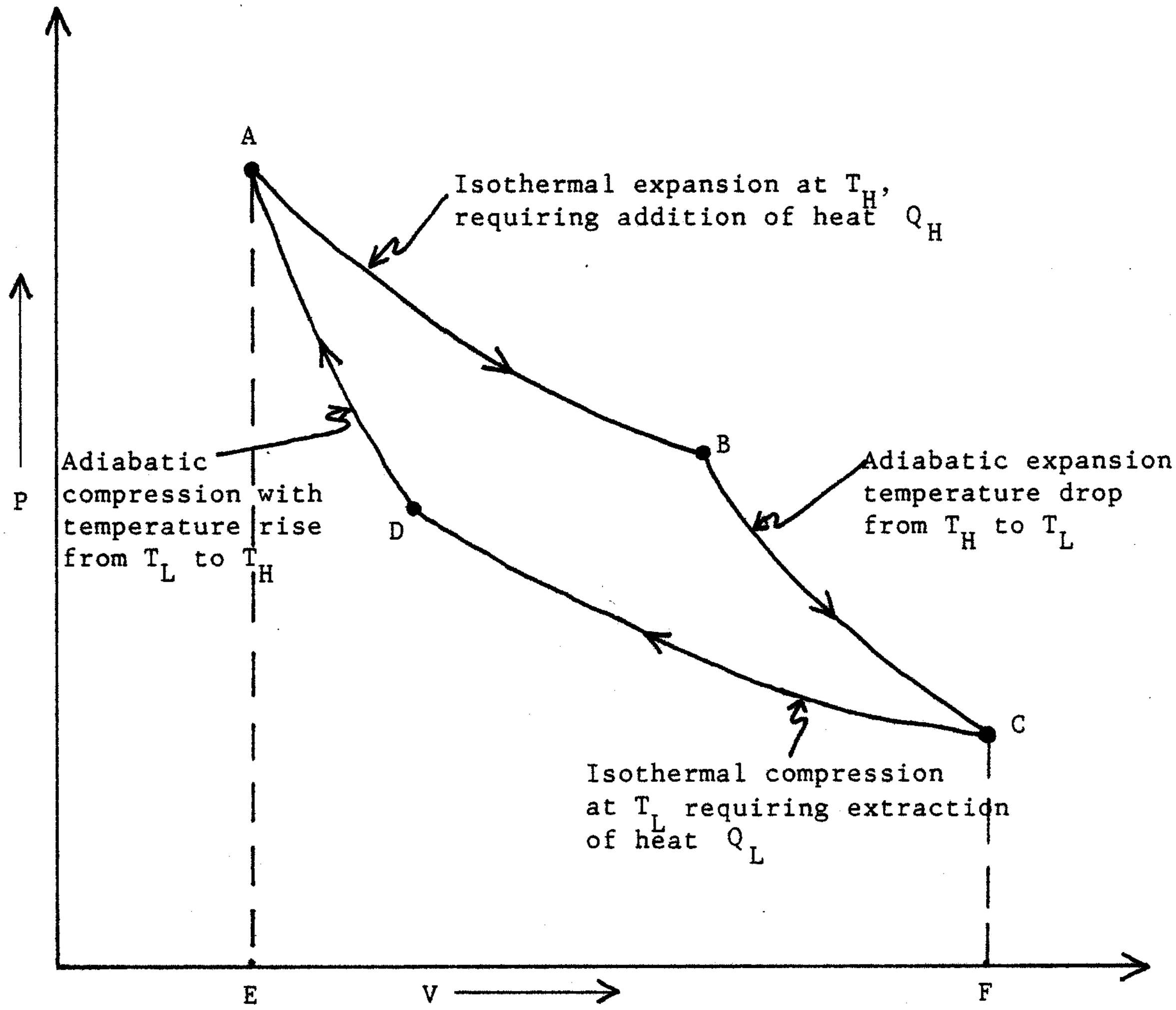
can be removed so that the gas and cylinder are in contact with the hot and cold heat reservoirs T_H and T_L, and isothermal processes can be used. Also assume that with the insulation in place, adiabatic process can occur. The Carnot cycle invovles two isothermal processes at T_H and T_L, and two adiabatic processes to carry the gas from the one temperature to the other.

Assume the initial state to be at P_A, V_A, T_H and identified as point A in the P-V diagram (Diagram 18). As the insulated end of the Carnot engine is removed, and the gas is in contact with the heat reservoir T_H, an isothermal expansion at T_H can occur. At the end of this expansion, the gas can be characterized by P_B, V_B, T_H and is point B on the graph. By replacing the insulation, the gas expands adiabatically until its temperature drops to T_L, and its state is P_C, V_C, T_L corresponding to point C on the graph. The work done in this adiabatic expansion is done by the reduction of the thermal energy of the gas since no heat is supplied from the outside.

Remove the insulation again, and the gas is in contact with T_L. The gas is compressed isothermally to volume V_D and pressure P_D (point D on the graph) and delivers heat Q_L to the heat reservoir T_L. As the

DIAGRAM 18[4]

Schematic Diagram of the Carnot Cycle



insulation is put back into place, the gas is compressed adiabatically to its initial state P_A, V_A, T_H, where its thermal energy is the same as it started and the whole cycle can be repeated.

The work done by the gas during the expansion is the area ABCFEA. External work done on the gas during compression is given by the area ADCFEA. The net work done by the engine during the cycle is the area ABCDA. In this ideal situation, the net work W done by the engine must be the difference in the heat Q_H supplied from T_H and the heat Q_L

delivered to T_L -- i.e., $W = Q_H - Q_L$, and $Q_H = Q_L + W$.

$$\text{The efficiency of the engine} = \frac{\text{useful work output}}{\text{heat input}}$$

$$= \frac{W}{Q_H} = \frac{Q_H - Q_L}{Q_H}$$

Carnot proved that for an engine of maximum efficiency

$$\frac{Q_H - Q_L}{Q_H} = \frac{T_H - T_L}{T_H}$$

where the temperatures are in Kelvin degrees. Hence, the efficiency ϵ is $\frac{T_H - T_L}{T_H} = 1 - \frac{T_L}{T_H}$.

To achieve an efficiency of 100% or 1, T_L must be absolute zero or 0 K. Thus a 100% efficient engine would reject no heat but would convert all the heat input into useful mechanical work. This is impossible, and the efficiency is much less than that. For example, if a steam engine has steam input at a temperature of 200°C, and is rejected at 100°C water, the efficiency of that heat engine is: $\frac{473\text{ K} - 373\text{ K}}{473\text{ K}} \times 100\% = 21\%$, and 79% of the heat would be carried away by the hot water. In actuality, frictional losses, etc. would further reduce the 21% efficiency. Obviously, the efficiency can be improved by making T_H higher and T_L lower.

The heat pump acts as a reverse heat pump in that it extracts heat from a cold reservoir, at temperature T_L, and supplies it to a hot reservoir at a higher temperature T_H. This operation requires mechanical work input. The energy balance can be read from Diagrams 17 and 19 and is $Q_H = W + Q_L$. The relationship between a heat engine and a refrigerator can be shown and summarized by the following figures 6 and 7.

DIAGRAM 19[5]

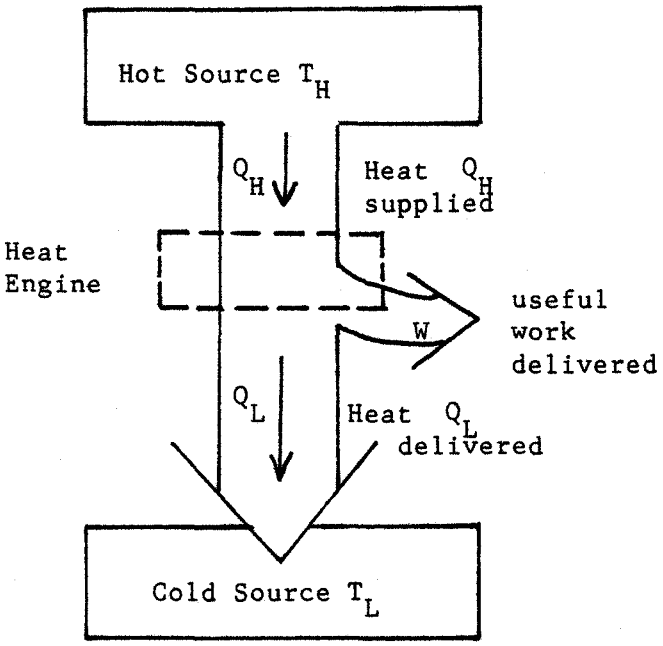


FIGURE 6: Schematic of a heat engine. Energy balance: $W = Q_H - Q_L$

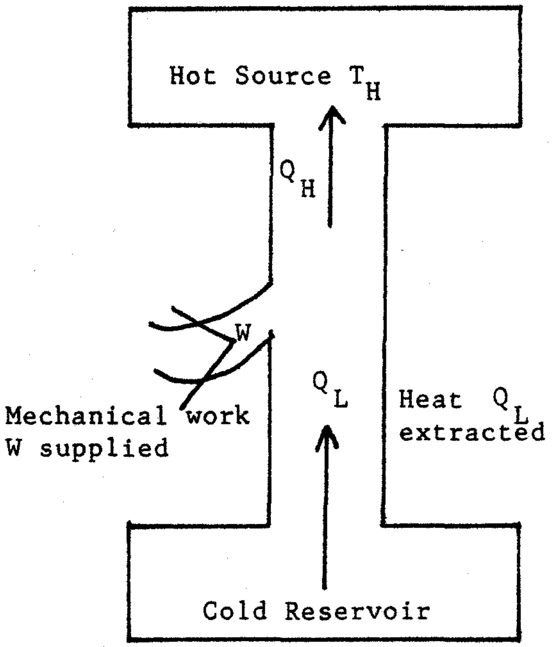


FIGURE 7: Schematic of a refrigerator. Energy balance: $Q_H = W + Q_L$

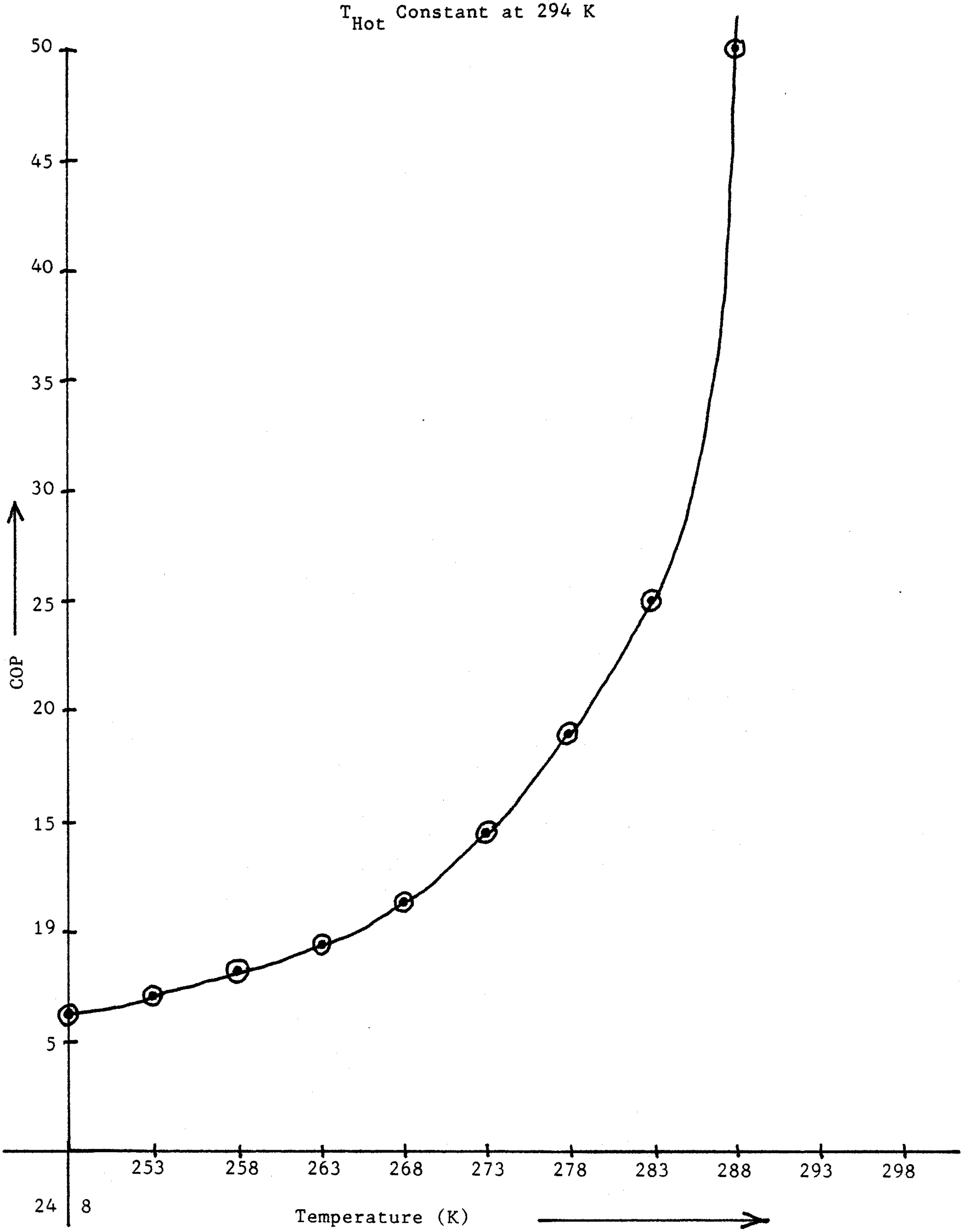
In dealing with heat pump efficiencies, one uses the coefficient of performance [COP] as the criterion of operation. The COP is defined as $\frac{\text{heat extracted}}{\text{work done}} = \frac{Q_H}{W}$ $\therefore$ COP $= \frac{Q_H}{Q_H - Q_L} = \frac{T_H}{T_H - T_L}$. It should be be noted that the coefficient of performance is the reciprocal of the Carnot efficiency.

Also: COP $= \frac{W + Q_L}{W} = 1 + \frac{Q_L}{W}$, and hence the COP is always greater than one.

Graph 16 illustrates how the theoretical COP varies with respect to temperature, with a fixed indoor temperature of 21°C [294K]. However, the heat exchange across the evaporator and condenser is never complete so that the ideal COP becomes significantly less than that shown on the

GRAPH 16

Graph of COP vs. Temperature with T_{Hot} Constant at 294 K



graph. Moreover, because one must work with real rather than ideal fluids, flow losses, compressor inefficiency, and frictional losses all combine to further reduce the achievable COP. The real situation will be discussed in Section D. However, it can be pointed out here that a real heat pump operating between temperatures where the ideal COP is 22.6 will have a COP of something between 2 and 3.

III SEASONAL PERFORMANCE FACTOR

To determine how efficient a heat pump is with respect to other heating systems, it is more useful to determine the seasonal performance factor which can be defined as:

$$\mathrm{SPF} = \frac{\text{Total heat delivered over heating season}}{\text{Total energy consumed over heating season}}$$

or

$$\mathrm{SPF} = \frac{[\mathrm{HPE}] + [\mathrm{AE}]}{[\mathrm{HPP}] + [\mathrm{AP}]}$$

where HPE = energy supplied by the heat pump during the heating season

AE = energy supplied by auxiliary electric heat during the heating season

HPP = energy required by the heat pump during the heating season

AP = energy required by auxiliary electric heat during the heating season

Note: Many heat pump manufacturers still use the unit Btu whereas electricity energy is measured in kWh. The conversion factor is 1 kWh = 3413 Btu.

A reasonable SPF of an electrically-driven heat pump is 3.0. However, electricity is normally produced by a steam turbine whose normal efficiency is approximately 35%. The transmission efficiency for the distribution of electricity is about 85% to yield an overall energy efficiency of 30% [.35 x .85 x 100]. By using a heat pump with an SPF of

3.0, this overall efficiency can be raised to 90% (i.e. 30 x 3 = 90). The overall efficiency of a fossil fuel-fired heating system is between 60% - 80%. Therefore, the heat pump with an SPF of 3 is from 13% ($\frac{10}{80}$ x 100) to 50% ($\frac{30}{60}$ x 100) more efficient than a fossil fuel furnace, and 200% ($\frac{60}{30}$ x 100) more efficient than straight electric heating. But the greatest advantage of the heat pump is that it can operate without fossil fuels (if one assumes electricity comes from hydro electric or nuclear energy sources), thereby considerably reducing the fossil fuel demand. As fossil fuel prices continue to rise, the heat pump becomes a more and more attractive alternative for home heating. Now that there is some agreement between Ottawa and the oil-producing provinces, it is anticipated that oil and natural gas prices will double in the next five years.[6] Electricity, which is more and more being derived from hydro and nuclear power is unlikely to rise this fast in Ontario. Ontario Hydro will only state that electricity prices will be competitive with other means of home heating.[7]

IV <u>BASIC HEAT PUMP DESIGNS</u>

There are three basic heat pump designs on the market today:

(1) air to air (single or split);

(2) air to water or water to air (single or split);

(3) air to ground (split).

Single-package heat pumps have all the essential components contained within a single unit while split-system heat pumps house the essential components in two separate units—one indoors, and one outdoors.

Basic designs are quite flexible and are readily adaptable to different types of applications. Heat pumps range in size from one ton (12,000 Btu's heating) to 50 ton or more. Each design has its own weaknesses and strengths:

(i) air system--the greatest problem is that low temperature air contains little heat, and at low temperatures the coils will frost over thereby greatly decreasing the efficiency of the system. In colder climates, a means of defrosting the coils must be used.

(ii) water system--the difficulty is that there must be a fairly large and steady supply of warm water. It also requires extra pumping.

(iii) ground systems--soil is a poor conductor, and ground shifts could result in loss of contact between the coils and soil, thereby greatly reducing the efficiency of the system.

All standard heat pumps have historically suffered from three basic deficiencies:

(i) poor reliability;

(ii) limited heating capacity in colder climates;

(iii) low seasonal performance factors.

However, these three factors can be improved with modern technology.

V ANALYSIS OF THE AIR TO AIR HEAT PUMP

Since the air to air heat pump is by far the most prevalent system installed in homes today, it warrants closer attention.

From Diagram 16 it can be seen that the heat pump cycle is quite easily reversed, which results in cooling or refrigeration. The direction is controlled by the four-way valve. This immediately produces a problem with heat pumps. The sizing is different for the heating and cooling functions, and a dual purpose system suffers reduced efficiency as a result of the necessary compromise. The dual-function heat pump is in fact not very suitable for a cold climate such as that of Southern Ontario. Since air conditioning can almost be considered a luxury in

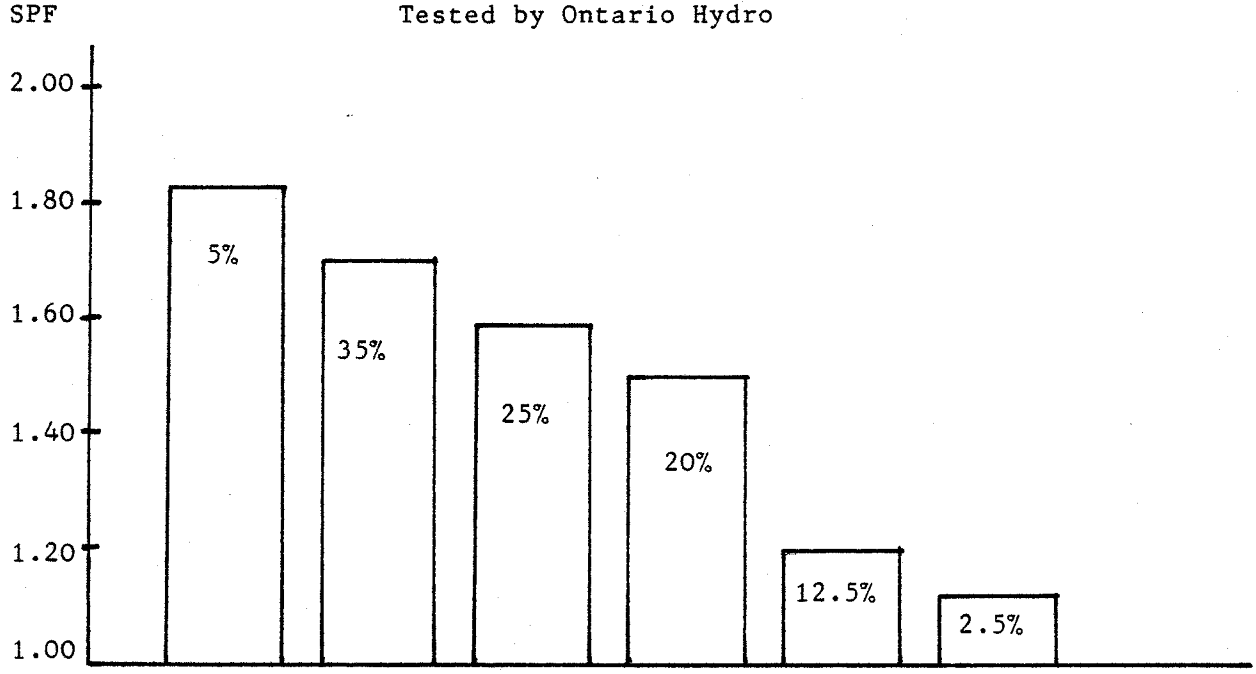
Ontario homes, pumps for this part of the world should be of the heat-only type. In contrast, in a large part of the United States, the air conditioning function is the more important one.

If a heat pump is sized for the heating load, it is oversized for air conditioning, and the excess capacity results in poor humidity control during cooling because the unit is cycled off for long periods of time.

Ontario Hydro has done two extensive research projects with heat pumps in new homes and old homes. Its first recommendation is that more research and development be done to develop a heat pump designed and manufactured primarily for the heating mode.[8] In the 1979 report it again concludes that oversizing greatly reduces the efficiency and that a heat-only pump should be developed.[9] The cooling period in our climate is much smaller than the heating period. The inefficiency of the dual-function heat pump is shown by the following table which lists the SPF of the heat pumps Ontario Hydro used for its study.

TABLE 18[10]

Seasonal Performance Factors of the Forty Heat Pumps
Tested by Ontario Hydro



the average SPF of the 40 installed units was 1.43, which is considerably below the SPF of 3 that was quoted earlier.

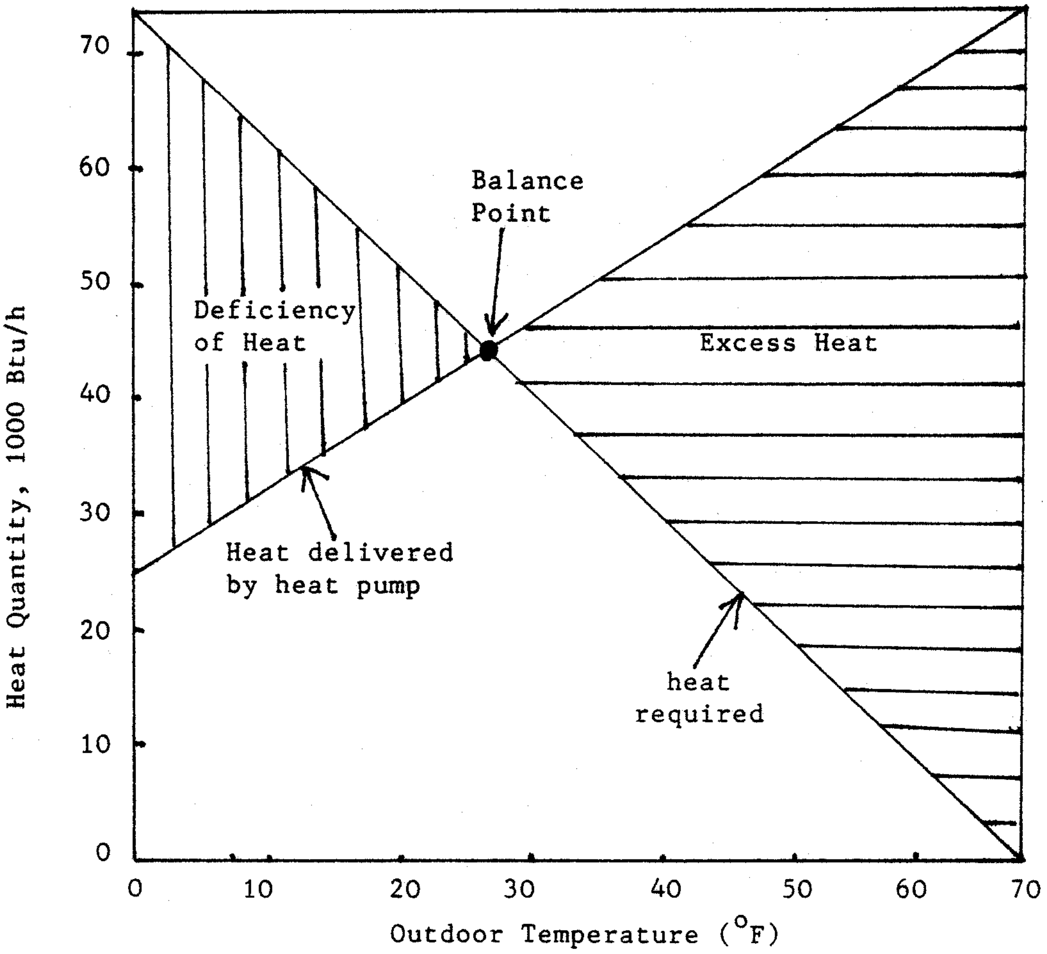
VI OPERATIONAL LIMITATIONS OF THE HEAT PUMP

A. Balance Point

Figure 8 is a chart which shows the heat delivered by the pump as a function of the ambient outside temperature and the heat required to maintain a 70°F (20°C) room temperature. The heat delivered at low ambient temperatures is less than that required while the heat delivered at high temperatures is greater than needed. For the low temperature region, the deficiency must be supplied by an alternative heating

FIGURE 8[11]

Heat Delivered by Heat Pump as a Function of the Ambient Temperature to Maintain a Room Temperature of 70°F or 21°C



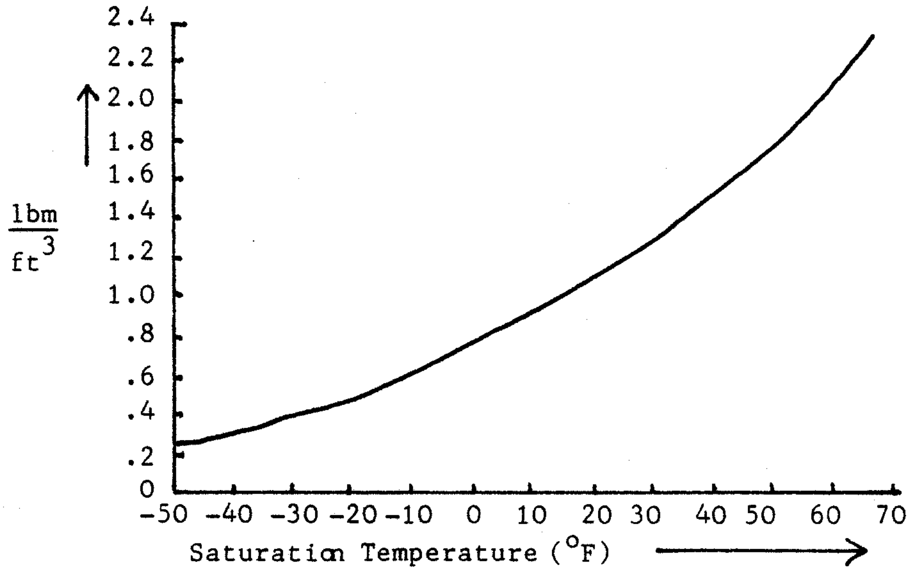
source; for the high temperature reading, the excess heat can be reduced by running the unit intermittently or by storing it for use when the outdoor temperature falls below the Balance Point, the point where the "heat required" and "heat delivered" curves cross. In Figure 8, this point is about 28°F or -2°C. The lower the balance point, the more economical the heat pump will be. In practise, the balance point is in the range of 28° to 32°F,[12] which means that about 30% of the heat during the winter months must come from an auxiliary unit (see data for Hamilton weather). One can install an oversized heat unit to bring the balance point lower, but this creates other problems, as subsequent discussion will reveal.

B. Capacity Mismatch

The capacity mismatch (heating and cooling) problem is primarily a result of changes in refrigerant mass flow rate due to density changes. The variation of saturated vapor density with saturation temperature for FREON 22 (refrigerant 22) is shown below.

FIGURE 9[13]

Variation of Saturated Vapor Density with Saturation Temperature--Refrigerant 22



As the ambient temperature increases, the saturation temperature and pressure inside the evaporator also increase causing vapor with greater density to enter the compressor which is almost a constant intake volume pump, and hence as the density of the gas entering increases, the mass flow increases. For example, between -30°F and +50°F, the mass flow rate increases by a factor of 4.7. The latent heat of vaporization is about constant, so that there is an increased amount of heat pumped from the outdoor ambient temperature into the space to be heated. The increase in mass flow also results in increased compressor work. The net result is that a greater amount of heat (compressor work and heat pumped from ambient air) must be rejected in the compressor. Thus for optimum efficiency, a heat pump should be designed either for the heating mode or the cooling mode. A compressor cannot be designed to operate at maximum efficiency for both heating and cooling since it experiences different pressure heads due to the different masses of gas moved in the heating and cooling mode. Today's heat pumps are designed primarily for the cooling mode. To bring the balance point down, oversizing is often used. But this is more expensive and brings with it the problem of humidity, because cooling requires a large drop in the indoor air temperature in order to dehumidify effectively and heating requires a small temperature rise to give a good COP.

C. Heat Transfer Across the Coils

The correct choice of heat exchangers (coils) and their sizing is probably the most important point in designing an efficient and economic heat pump. Efficiencies are greatly decreased by the resistance to heat transfer at the air-side coils. The simple heat transfer processes at either coil can be written as

$$q = UAdT$$

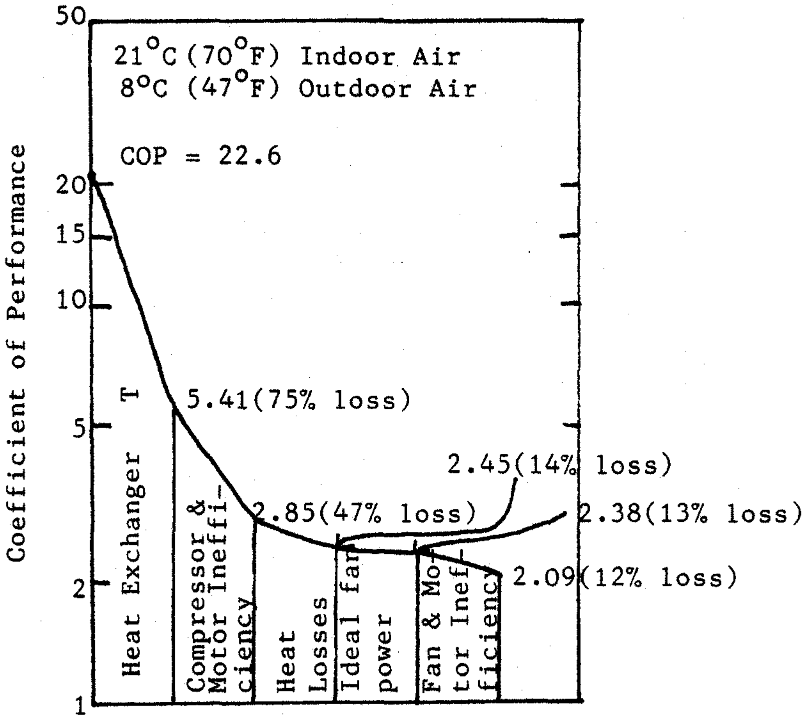
where q is the heat flow, U is the heat transfer coefficient, A is the effective heat transfer area, and dT is the average effective temperature difference. U is constant for a given design of a heat pump. Hence, for a maximum heat flow for a given U, both A and dT should increase. A is frequently increased by increasing the surface area in the form of fin-like structures. The temperature difference dT should also increase, but this increases the irreversibilities in the cycle, and a drastic reduction from the theoretical maximum COP's, as discussed in the next section. For heat transfer between refrigerant and air or vice versa, the air is usually forcibly circulated by fans over the finned coils.

D. Summary of Other Factors

Other factors that decrease the efficiency of the heat pump are summarized in Graph 17 below:

GRAPH 17[14]

Effect of Component Inefficiencies on System Efficiency Under Steady-State, Nonfrosting Conditions



The theoretical COP is $\frac{294}{13} = 22.6$. The major loss occurs across the heat exchangers. For heat to be absorbed, the refrigerant in the evaporator coil should be lower than the ambient temperature. Let the refrigerant temperature be $-10^{\circ}C$. Also the temperature of the refrigerant in the condenser should be greater than $21^{\circ}C$--let it be $50^{\circ}C$. Now the COP has been reduced to $\frac{273 + 50}{323 - 263} = 5.4$. If the temperatures become $-5^{\circ}C$ and $45^{\circ}C$, then the COP is 6.4 $(\frac{318}{50})$ which is better. However, as was stated in the previous unit, the heat transfer is increased if the temperature difference dT increases. Hence, these two parameters oppose each other, and an optimum must be established that gives a reasonable heat transfer and COP.

The motor plus compressor efficiencies depend to a certain degree on the size of motor and compressor. Large units can have an efficiency of up to 70%. Most residential units are smaller and have an efficiency of 40-60%. The chart indicates an efficiency of 53%.

Heat losses will occur along the path travelled by the refrigerant, and fan efficiency further reduces the ideal COP, so that the final or actual COP is about two which is great reduction from the ideal COP of 22.6. It indicates that more work can be done on the heat pump--such as the heat-exchanger system and compressor--to improve the actual COP of the heat pump.

E. Recommendations

To make the heat pump a more viable and feasible unit for home heating, a number of factors ought to be researched. Improvements should be made. In major studies conducted by Edison Electric Co., U.S.A., and Ontario Hydro, a number of recommendations were offered to improve the performance of heat pumps. The major recommendations are:

(1) improve the heat exchanger surfaces;

(2) develop a heat pump only for the heating mode in colder climates;

(3) improve controls, such as defrost timers, etc.;

(4) improve compressor design;

(5) improve reliability of the entire system;

(6) improve repair service record.

Europe is the leader today in the research and development of heat pumps. Sweden, the Netherlands, England, and Germany are actively involved in producing more efficient heat pumps. North America is just starting. Fierce international competition could well be a major feature of heat pump developments in the 1980's.

F. Refrigerant Properties

The refrigerant is the most important element in the vapour compression cycle. Heat is collected and released by changes of state of the refrigerant, and is moved by its circulation. The choice of refrigerant depends firstly on its boiling point, temperature, and pressure so that heat can be transferred within a practicable pressure range, and secondly on its latent heat property so that enough energy can be pumped efficiently. These can be called the thermodynamic criteria. The refrigerant must also meet safety criteria--flammability, toxicity, etc. Technical criteria (action on metals, tubing, oils, etc.) must also be met. The economic criteria (cost, availability) must also be considered--the cheaper the better, if the other criteria are equivalent. Some properties of the most common refrigerants are given in Table 19.[15]

Generally speaking, Avogadro's Law (for all ideal gases the volume of one mole of a gas at STP is a constant) and Trouton's Rule (the ratio

TABLE 19

Refrigerant Number	Formula	Molecular Weight	Boiling Point °C	Critical Temp. °C	Vapour Pressure at 90°C bar	Latent Heat of vaporization KJ/kg
R11	CCl_3F	137.38	23.8	198.0	6.66	182.0
R12	CCl_2F_2	120.9	-29.8	112.0	27.88	165.1
R22	$CHClF_2$	86.5	-40.8	96.0	44.42	234.1
R113	$C_2Cl_3F_3$	187.39	47.6	214.1	3.44	146.7
R114	$C_2Cl_2F_4$	170.94	3.6	145.7	11.51	137.2
R115	$CClF_2CF_3$	154.5	-38	115.3	16.27	151.1
R500	R12 + R152a	99.3	-33.5	105.0	28.76	205.8
R502	R22 + R115	111.6	-45.4	82.2	21.32	172.5
R718	H_2O	18.0	100	374.2	0.692	2257

of the molar heat of vaporization of a liquid to its normal boiling point on the absolute scale is a constant, the same for all liquids--$\frac{\Delta H_v}{T_b}$ = constant) indicate that for a given compressor, and for given condensation and evaporation temperatures, there will be no wide variations in heat pumping capacity between different refrigerants. Thus other factors such as chemical stability, toxicity, availability and cost become more important.

But if a refrigerant is chosen for a particular climate such as Southern Ontario, then the refrigerant must have a sufficiently low boiling point to cover a range of evaporating temperatures from -35° to 20°C. The critical temperature must also be high enough for the gas-liquid phase to be maintained in the system. The vapour pressure should be low enough that no complex and costly construction be necessary to keep the refrigerant within the system. The latent heat per kilogram of refrigerant should be sufficiently high to keep the amount of refrigerant to be pumped within reasonable limits. From the data above it can be seen that R12 and R22 are obvious choices as refrigerants, with R22 being the top choice. R22 is the most common refrigerant in heat pumps. It is also relatively insoluble in lubricating oils, but is a destructive solvent for wire enamel, varnish, and elastomeric seals. It also operates at a rather high vapour pressure. Research is continuing in developing a refrigerant that can operate at preferred temperatures of -40° to +15°C and at a practicable pressure, and be inert to the various components in the heat pump unit. R502 overcomes some of these deficiencies of R22 but it is more expensive, and requires larger pipework due to increased pumping rates. R114, R11, and R113 are good refrigerants for heat pumps operating at higher condensing temperatures, and may be suitable for upgrading heat from solar collectors.

G. Duct Size

One other factor must be mentioned. The refrigerant does not carry as much heat/given volume as can be obtained by burning a similar volume of oil or natural gas. Therefore, to obtain the equivalent amount of heat, much more refrigerant gas must be moved and more air must be circulated, which requires large air ducts in homes. Industry recommends at 8" duct. In older homes, there is a duct work of 4" or 5" diameter, and it should be replaced, if possible.

VII THE HAMILTON CLIMATE

A. Weather Data for the Last Twenty Years

The efficiency of the heat pump is directly related to the climate. The weather data for Hamilton over the last twenty years are tabulated and graphed as mean temperature vs. time (month). The months in which heat is required is dependent on the individual's demand for comfort. If extra heat is needed when the outside temperature falls below 13°C (55°F) then the heating season (to the left and right of the vertical dashed lines) is about eight months per year long. If a person

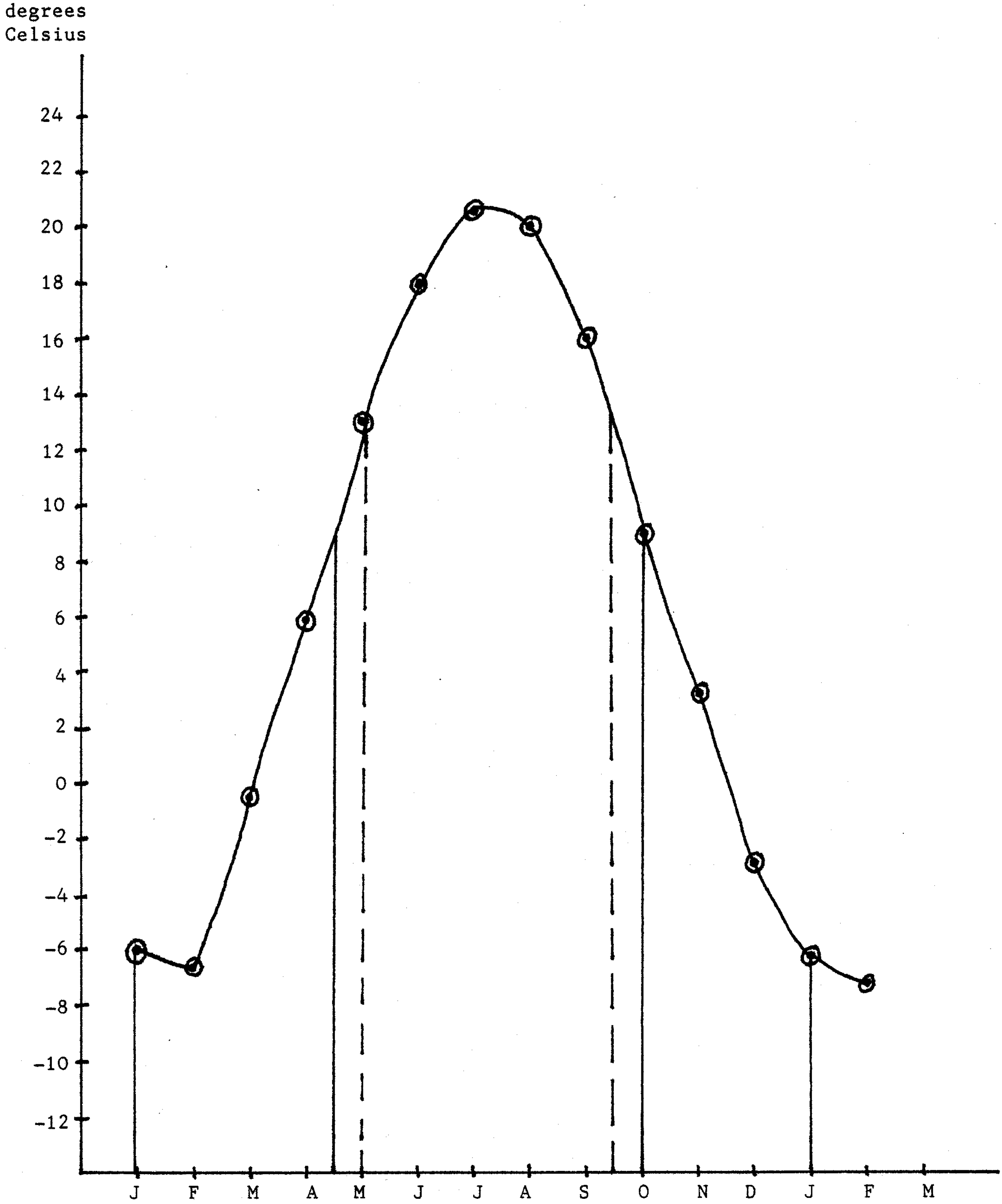
TABLE 20[16]

Mean Temperatures of the Hamilton Climate per month for the Years 1962-1981

Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
1962	- 5.6	- 5.8	1.1	8.1	15.9	18.8	20.3	20.5	15.0	10.5	3.0	-3.7	°C
1963	- 5.4	- 6.0	.50	6.7	13.2	17.8	21.2	20.2	16.0	9.8	3.8	-2.7	
1964	- 4.4	- 6.5	.94	6.3	14.8	18.2	22.6	18.3	16.2	9.2	5.5	-1.3	
1965	- 5.2	- 6.9	- 1.3	4.4	14.2	18.3	19.1	20.0	17.2	8.9	4.6	1.0	
1966	- 5.8	- 6.0	0	6.2	13.0	18.0	20.5	20.0	16.1	9.4	3.4	-2.7	
1967	- 2.5	- 7.8	- 0.83	6.7	9.3	17.2	20.6	19.3	15.4	10.3	2.6	-0.33	
1968	- 3.7	- 7.6	0	8.3	10.3	17.1	20.3	20.1	17.8	10.9	3.2	-3.9	
1969	- 5.4	- 4.6	- 1.5	7.6	12.4	16.9	21.1	21.6	16.6	9.4	3.4	-5.4	
1970			- 1.8	7.7	14.1	18.8	21.7	21.5	17.1	11.8	4.3	-3.7	
1971	- 7.7	- 4.7	- 2.6	5.3	12.5	19.7	20.1	19.7	17.7	13.3	3.1	-0.3	
1972	- 5.1	- 6.9	- 3.2	3.8	14.2	16.3	20.8	19.3	16.3	6.8	1.4	-2.0	
1973	- 6.9	- 7.2	3.4	6.4	11.1	19.2	21.2	22.2	16.3	11.3	3.8	-3.7	
1974	- 4.8	- 6.7	- 0.55	7.4	10.6	17.7	20.6	20.5	14.2	7.9	3.7	-1.4	
1975	- 2.7	- 3.6	- 2.4	3.4	16.1	18.9	21.1	19.7	13.3	10.4	7.1	-3.7	
1976	- 9.1	- 2.0	1.3	7.9	11.1	19.7	19.5	18.7	14.6	6.5	-0.3	-7.2	
1977	-11.8	- 5.8	2.4	7.7	15.2	17.2	21.2	18.9	16.1	8.8	4.3	-3.7	
1978	- 8.0	-10.3	- 4.0	4.9	12.9	17.7	20.1	20.3	15.6	8.5	3.2	-2.4	
1979	- 7.7	-10.5	1.8	5.7	11.8	17.5	20.8	18.9	15.6	8.6	4.1	-0.6	
1980	- 5.0	- 7.4	- 2.0	6.4	14.0	15.9	20.9	21.7	15.7	7.0	1.9	-5.7	
1981	- 8.9	- 2.1	0.4	7.4	12.3	18.1	20.7	19.8	14.9	7.1	3.9	-2.5	
Average	- 6.1	- 6.3	- .48	6.4	12.9	17.9	20.7	20.1	15.9	9.4	3.5	-2.8	°C

GRAPH 18

Graph of Mean Temperature vs. Month
for Hamilton Climate



can accommodate himself to some discomfort and not call upon extra heat until the outside temperature is about 10°C (50°F) then the heating season (to the left and right of the solid vertical lines) is about seven months per year long.

B. Temperature vs. Number of Hours

It is more useful to determine the number of hours/year that the temperature is below the balance point. The data for the years 1957-66 for the Hamilton climate are given in the table below. Below each temperature, the number of hours per year for which the temperature was within two degrees of the stated temperature is given:[17]

Outdoor Temp.	62°F	57°F	52°F	47°F	42°F	37°F	32°F
Hours	739.5	718	796.3	627.9	593.5	718.4	876.7

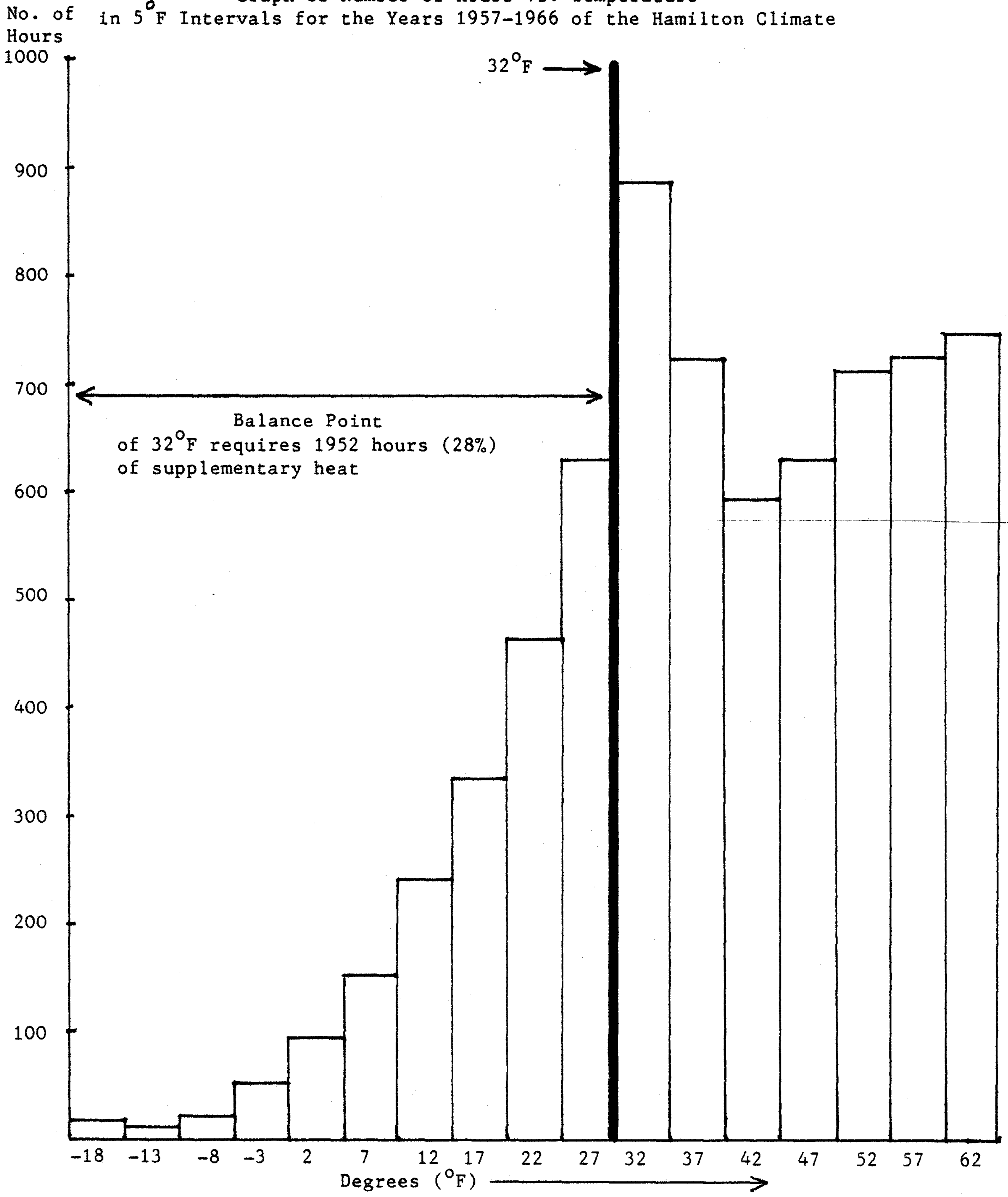
Outdoor Temp.	27°F	22°F	17°F	12°F	7°F	2°F	-3°F
Hours	634.1	461	331.9	239.8	146.7	91.4	35.5

Outdoor Temp.	-8°F	-13°F	-18°F
Hours	10.1	0.8	0.1

The above data are plotted on the following Graph 19. It can be seen from the graph that for most of the time, the temperature is above 32°F, and that if a heat pump had a balance point of 32°F supplementary heat would be needed for 1952 hours or 28% of the time. But if the balance point were lowered to 27°F, then supplementary heat would be needed for only 1318 hours or 19% of the time. With an oversized air to air heat pump, this balance point of 27°F is attainable today. Thus, for the Hamilton climate, a heat pump should be able to supply about 80% of all

GRAPH 19

Graph of Number of Hours vs. Temperature in 5°F Intervals for the Years 1957-1966 of the Hamilton Climate



the necessary heat required to heat a home during the heating season.

C. The Economics of a Heat Pump

A number of calculation will show the feasibility of installing a heat pump. To heat an average home today with oil will cost about $800. To this must be added the cost of electricity of running the motor and fan. Assume that the fan-motor combination is rated at 500 Watts (2/3 H.P.). Further assume that the furnace runs about six hours per day during a heating season of seven months. At a cost of 4¢/kWh, this electricity cost is:

$$\frac{6\ \text{h}}{\text{day}} \times 500\ \text{Watts} \times \frac{1\ \text{kW}}{1000\ \text{W}} \times \frac{4\ \text{cents}}{\text{kWh}} \times 213\ \text{days} = \$25.56$$

Hence, the total heating bill is about $825.

If a heat pump is used, 20% of the heat must come from oil, or about $200. However, the heat pump will use from 6000-7000 kWh of electrical energy[18] at a cost of $240-280. Hence, the total heat pump cost is about $450, which represents a net saving of $400/year. The cost of installing a heat pump is about $3,000 which is thus recovered in about seven to eight years.

Another advantage is, of course, that oil consumption is reduced by 80% which is a very considerable step in conserving this fossil fuel. One other observation must be made. The cost of electricity will increase at annual rate slightly below the annual rate of inflation.[19] Oil and gas prices will rise much faster. It is projected that in about five years, electrical heating will be cheaper than oil or gas. Thus, a heat pump with an electric-heat back-up unit will not only be cheaper but will also further reduce oil or gas consumption. Such a system should be recommended especially for the new housing industry in Southern Ontario.

NOTES - CHAPTER THREE

1. M.J. Collie, Heat Pump Technology for Saving Energy, Noyes Data Corp., 1979, p. 4.

2. Ibid., p. 15.

3. Adapted from G. Shortley and D. Williams, Elements of Physics, 4th edition, New Jersey: Prentice-Hall, Inc., 1965, pp. 395-396.

4. Ibid., p. 396.

5. Ibid., pp. 397-398 (adapted).

6. Globe and Mail, September 1, 1981.

7. Private communication from Ontario Hydro.

8. Ontario Hydro, E.D.C. Report No. 77-4, p. 3.

9. Ontario Hydro, E.D.C. Report No. 79-3, p. 25.

10. Ontario Hydro, E.D.C. Report No. 77-4, p. 2.

11. D.N. Lapedes (Ed.), Encyclopedia of Energy, McGraw-Hill, 1976, p. 384.

12. Obtained from literature supplied by various companies such as Amana Corporation, Carrier, Lennox, C.G.E.

13. Collie, op. cit., p. 22.

14. Ibid., p. 273.

15. R.D. Heap, Heat Pumps, John Wiley Publishers, 1979, p. 38.

16. Environment of Canada, Annual Meteorological Summary 1962-1981, Hamilton and Mount Hope.

17. Data supplied by the Climatology Division, Meteorological Branch, Department of Transport, Ottawa.

18. Data supplied by D. Crump, Toronto.

19. House of Commons Special Committee on Alternative Energy and Oil Substitution, T. Lefebvre (Chairman), Energy Alternatives, Ottawa, 1981.

CONCLUSION

Chapter One has attempted to show that there is no longer any doubt that our age of affluence based upon the depletion of our planet's non-renewable energy and material resources is at an end and that major changes must be made in every aspect of our lives. Our affluence and wealth have been made possible because of the great amount of work done for us by the non-renewable fossil fuels. Also, global population is still increasing beyond what can be sustained at our present standards of living and this is making greater demands for these increasingly limited resources. Certain political actions (such as cost) are also taken to slow the rate of consumption of fossil fuels which further decreases the availability of fossil fuels to the Third World countries.

The reality must be faced that any attempt to sustain our growth, or even to maintain our present style of life without basic changes will result in a steady and perhaps catastrophic worsening of our quality of life. The assumed plentiful resources have until now kept us free from making hard decisions. Our present society is based on the condition that there is and that there will be plenty of relatively cheap energy. However, these dreams might now be unattainable, and society must now be educated that hard decisions must be made now.

Countless times have we been told that growth is necessary for the health and well-being of our economy and our society, which is true because if growth and consumption stop--as it seems they have--our society based largely on economics will come apart. But Chapter One tells us that growth must stop and that we must consume less. The resultant radical change in societal structure is unavoidable and necessary, and is required in our every action and value that underlies that action. We will have to critically examine the nature and effects of our institutions and impose restraint on those that lessen the quality of life, or have a negative effect on society as a whole. The agricultural revolution discussed in Chapter One is a good example. And it should be remembered that the rsponsibility to perceive misdirections of societal institutions and the power to correct these misdirections cannot be replaced by the most sophisticated computer. Man is obliged to exercise proper stewardship over nature.

The energy crisis demands the proper energy ethic that a reduction in energy consumption by all sectors of society is feasible and absolutely necessary if we are to buy the time necessary to develop alternative energy sources and to make necessary economic and social adjustments. The energy crisis is real and alternative sources must be developed.

The second chapter discusses a number of alternative sources that can be employed to reduce our demand on fossil fuels. Nuclear energy in the production of electricity seems a very viable option for Ontario. Also, hydrogen might have a considerable impact on the future energy demands since its production can be aligned so effectively with the constant production of electricity in Ontario.

The private citizen consumes about 40% of all energy used, and he must adopt a proper energy ethic that can be transferred to the next generation which is composed of today's students. Two areas where a person can conserve energy are transportation and home heating. Hence, Chapter Three examines the feasibility of the heat pump as a home heating device for the Southern Ontario climate.

Adjustment to a lower rate of energy consumption and to alternate sources of energy does not necessarily mean hardship and discomfort. Compulsive consumption must be exchanged for a proper stewardship of the earth's resources that ultimately leads to a stable and satisfactory lifestyle applicable to all people on earth.

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APPENDIX

TABLE 1: METRIC PREFIXES
TABLE 2: TIME CONVERSIONS
TABLE 3: POWER CONVERSIONS
TABLE 4: ENERGY CONVERSIONS
TABLE 5: GENERATION VALUES
TABLE 6: THERMAL INSULATION (R-values/thickness)
TABLE 7: CONSUMPTION VALUES (Approximate)
TABLE 8: SUNLIGHT (ENERGY AND ENERGY/AREA)
SUNLIGHT (POWER/AREA)

(The 8 tables listed above were taken from: The Physics Teacher, September, 1981, pp. 381-383.)

TABLE 1: METRIC PREFIXES

Prefix	Abbreviation	Factor
exa	E	10^{18}
peta	P	10^{15}
tera	T	10^{12}
giga*	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
hecto	h	10^{2}
deca	da	10
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}
atto	a	10^{-18}

(*pronounced jiga)

TABLE 2: TIME CONVERSIONS

Units	Seconds
minute	60
hour	3600
day	8.64×10^{4}
year	3.16×10^{7} ($\sim\pi \times 10^{7}$)

TABLE 3: POWER CONVERSIONS

Thermal and Mechanical Units

Consumption Figures

	Watts
BTU/s	1054
BTU/hour*	0.293
1 quad/year	3.35×10^{10}
horsepower	746
joule/s	1
kilowatt	10^3
kilowatt hours per day	41.7
kilocalories per hour	1.16
kilocalorie/day	4.84×10^{-2}
ft lb/min	2.26×10^{-2}
standard ton of refrigeration	3513
gallon of oil per minute	2.5×10^6
gallon of gasoline per hour	39×10^3
million barrels of oil per day	73×10^9

(*sometimes written confusingly as BTUh.)

TABLE 4: ENERGY CONVERSIONS

Unit	Joules
Mechanical Units	
foot pound	1.36
erg	1.0×10^{-7}
horsepower hour	2.69×10^{6}
watt-year	3.16×10^{7}
watt-second	1
kilowatt hour (kWh)	3.6×10^{6}
Atomic, Molecular and Nuclear Units	
electron volt (eV)	1.6×10^{-19}
fission energy of U^{235}	3.2×10^{-11}
kilogram of matter entirely converted to energy	9.0×10^{16}
million electron volt (MeV)	1.6×10^{-13}
Tydberg	2.8×10^{-18}
cm^{-1} (photon energy $\propto \lambda^{-1}$)	1.98×10^{-18}
kg of U^{238} energy available if made fissile	8.1×10^{13}
Thermal Units (thermochemical)	
calorie	4.184
kilocalorie (Calorie)	4184
British Thermal Unit (BTU)	1054
Quad (=10^{15} BTU)	1.054×10^{18}
Therm (=10^{5} BTU)	1.054×10^{8}
Units of Stored Chemical Energy * (± few percent)	
Quantity	Joules
barrel of oil	6.3×10^{9}
gallon (U.S. of oil**	1.5×10^{8}
gallon (U.S. of gasoline**	1.4×10^{8}
gallon of alcohol (ethanol)	9.5×10^{7}

Quantity	Joules
pound of petroleum fuel**	2.1×10^{7}
pould of coal	1.45×10^{7}
ton of coal	2.9×10^{10}
tonne (metric ton) of coal	3.2×10^{10}
mtce (million tons of coal equivalent)	3.2×10^{16}
cubic foot (atm. press. 15.6°C) natural gas	1.1×10^{6}
ton of TNT	4.2×10^{9}
cord of white oak+	3.1×10^{10}
cord of western white pine+	1.7×10^{10}
pound of wood+	8.6×10^{6}
pound of dried grass	6.9×10^{6}
kg of dried grass	1.5×10^{7}
pound of fat	1.7×10^{7}
kg of fat	3.75×10^{7}

(*High heat values; **on a per-pound basis, all petroleum fuels contain approximately the same energy; +on a per-pound basis, all woods contain approximately the same energy.)

TABLE 5: GENERATION VALUES

		Power in watts	Joules/yr
Typical large electrical generating plant		1×10^9	
Grand Coulee Dam (Washington)	(present)	4×10^9	
	(ultimate)	10×10^9	
Norris Dam (Tennessee)		0.15×10^9	
All U.S. Dams	(present)	57×10^9	
	(ultimate)	185×10^9	
World's largest windmill, Boone, NC	(12.5 m s^{-1})	0.002×10^9	
	(9.8 m s^{-1})	0.001×10^9	
	(4.8 m s^{-1})	0.0001×10^9	
Typical western windmill, average		500	
Human labor, bicycle-seat	(very briefly)	1000	
	(continuously for day)	100	
Biomass:	1 lb dry matter/yr	0.24	
	1 kg dry matter/yr	0.53	
U.S. food crops, total (as food)		150×10^9	4.8×10^{18}
U.S. combustible wastes	(total)	315×10^9	9.9×10^{18}
	(agricultural)	240×10^9	7.6×10^{18}
	(urban)	55×10^9	1.7×10^{18}
	(collectible total)	60×10^9	1.9×10^{18}
Waterfall:			
1200 m^3/s	100 m (85% eff)	1.0×10^9	
$69,000$ ft^3/s	200 ft (85% eff)	1.0×10^9	
Windmills: $P = 0.64 \quad A v^3$ (SI)			
61 m (200 ft) diam, 9.8 ms^{-1} (22 mph wind)		0.001×10^9	

TABLE 6: THERMAL INSULATION (R-values/thickness)

Material	$\frac{m^2\,{}^{o}C}{Watt \cdot m}$
Urethane, foamed in palce	58.7
Urethane foam, sprayed in place	41.5
Molded Polystyrene foam	32.3
Fiberglas	27.7
Rock wool, loose fill	23.1
Insulation board, impregnated	18.3
Vermiculite, expanded	14.4
Plywood	8.7
Softwoods	8.7
Hardwoods	6.9
Plaster board	5.9
Concrete, lightweight aggregate	2.6
Brick (face)	0.8
Concrete, sand, gravel aggregate	0.6

R-values	$m^2\,{}^{o}CW^{-1}$
$ft^2 \cdot F \cdot hr \cdot BTU^{-1}$ (R-1)	0.176
3 1/2 in. Fiberglas insulation (R-11)	1.84
R-19	3.17
R-30	5.01

Heating Demand

	${}^{o}C \cdot s$
1 degree-day (^{o}F-day)	48,000
1 ^{o}C-day	86,400
3333 ^{o}C-days (6000 ^{o}F-days)	2.88×10^8

TABLE 7: CONSUMPTION VALUES (APPROXIMATE)

		Watts
Per capita power use (all sources)	(world)	2000
	(U.S.A.)	10,500
U.S.A. power use (electrical)		250×10^9
(total)		2600×10^9
(for operating all clocks)		1×10^9
(two 100-W bulbs/household)		10×10^9
Automobile at 27 ms^{-1} (60 mph) 12.8 km/	(30 mpg)	
	(thermal)	80×10^3
	(mechanical)	20×10^3
Heating, well insulated 3-bedroom house, $T_{out} = -18^\circ C$ ($0^\circ F$)		11,000
Average for 3333°C-days (6000°F-days) in 6 months		6000
Water heating: 378 kg (100 gal), 10°C to 66°C daily		1000
Air heating: 0.028 $m^3 s^{-1}$ (1 $ft^3 s^{-1}$), -18°C to 21°C		1000
Human caloric consumption (average adult)		
	average consumption	110
	sleeping	70
	walking	250
	horseback riding (trot)	550

TABLE 8

SUNLIGHT (ENERGY AND ENERGY/AREA)

Yearly U.S. sunlight	6×10^{22}J
Langley (=1 cal/cm^2)	4.184×10^4 J/m^2
Average of 100 Langleys/day for year	1.52×10^9 J/m^2
Yearly sunlight, Connecticut	5×10^9 J/m^2
Yearly sunlight, Denver	6.7×10^9 J/m^2
Yearly sunlight, Albuquerque	7.6×10^9 J/m^2

SUNLIGHT (POWER/AREA)

	watts/m^2
Incident upon earth, above atmosphere on surface facing sun	1353
At surface, clear sky, on surface facing sun, sun overhead	950
100 Langleys/24 hours	48.4
Yearly average, available sunlight, horizontal surface, Connecticut	160
Yearly average, available sunlight, horizontal surface, Albuquerque	240
Yearly average, horizontal surface, U.S.A.	200

Biomass (all figures ignore energy used in production). Butning biomass produces:	watts/acre	watts/m^2
U.S.A. average crop production, edible portion	460	0.114
Wood (Untended hardwood)	500	0.125
(cultivated for paper, South)	5500	1.35
Corn -- whole plant	3000	0.75
edible	1000	0.25
as alcohol	550	0.14
Sugar cane (experimental, whole plant)	25000	6.2
at maximum theoretical efficiency (6%)	53000	13
Oceans at maximum theoretical efficiency (0.3%) (plankton)	2500-3000	0.62-0.74
Oceans at maximum theoretical efficiency (0.3%) (fish)	25	0.0062