THE UNIVERSITY OF MANITOBA

AUTONOMOUSLY SERVICED SETTLEMENTS

BY

DAVID W. F. WIDDOWS

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF CITY PLANNING

WINNIPEG, MANITOBA
MAY 1987

ISBN 0-315-37419-5

AUTONOMOUSLY SERVICED SETTLEMENTS

BY

DAVID W.F. WIDDOWS

A thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF CITY PLANNING

ACKNOWLEDGEMENTS

The author wishes to thank Professors Mario Carvalho, John Welch and especially Basil Rotoff for their help and guidance throughout the preparation of this thesis.

At the end of this long and sometimes frustrating period special thanks must be given to my wife Arlene for her tireless support and firm belief that it could be completed and done well. This thesis is dedicated to her.

Winnipeg, Manitoba
May 1987

ABSTRACT

This thesis investigates the hypothesis that an autonomously serviced settlement i.e. one that generates its own heat and power by utilizing alternate forms of energy can be established. It deals specifically with remote communities that depend upon expensive diesel (fossil) fuel as their prime source for heat and electricity.

The importance of energy is reviewed in conjunction with the problems caused by the Arab oil boycott of the late 70's and early 80's and the diminishing world reserves of fossil fuels. Renewable energy sources such as solar, wind, geothermal, biomass and nuclear energy are proposed as alternates to fossil fuels. Each resource is reviewed by outlining their historical development, principles of operation and those systems that are on the market today.

A case study is used to support the hypothesis. The energy requirements of a small remote community are detailed to show that these alternate forms of energy can provide for the electrical and space heating needs. Installed costs of the systems are compared to evaluate the alternatives. The thesis conclusion outlines the prospects for these energy systems and recommends the system best able to provide the energy needs for the community. It concludes by proposing a checklist that would be of benefit to planners when considering energy systems for existing and new remote communities.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

LIST OF TABLES

LIST OF FIGURES

AUTONOMOUSLY SERVICED SETTLEMENTS

CHAPTER ONE

INTRODUCTION

PURPOSE STATEMENT

The energy crises of the early 70's alerted Canada, the United States and the rest of the world to the end of the era of inexpensive energy. At the present time world-wide energy consumption outstrips production. It is estimated that the recoverable reserves of fossil fuels such as oil and natural gas will only last to the first decades of the 21st century. Alternately they will be so expensive to mine and produce that fossil fuels will no longer be a viable means of providing the energy we need.

Interest in and research on the development of alternate energy sources - such as solar, wind and biomass - have significantly increased over the past decade. The National Energy Program has stated that remote communities are prime candidates for alternative energy due to their dependence upon expensive fossil fuels combined with high delivery costs.[1] The technology to effectively utilize these sources is available today. We are now able to answer the following question with confidence:

Can an autonomously serviced settlement be built in Canada now, with systems already on the market, which would show that the energy and material basis of housing can be shifted from non-renewable to renewable materials and resources? [2]

In this regard, a small Manitoba Inter-Lake town will be used as a case study to verify the purpose statement. This small self-contained town is Canadian Forces Station Gypsumville, a radar site in the Mid-Canada radar chain located 160 road miles north of Winnipeg.

BACKGROUND

Context

The era of the late 50's, 60's and early seventies could be characterized by the emergence of the industrial megalopolis whose creation was made possible by cheap and abundant energy. Energy and resource conservation were terms unheard of in the halls of major corporations or indeed in the industrial nations of the world.

The oil crises of the 70's brought a realization that current energy resources were being depleted at an alarming rate. It was evident that, if current inefficiencies in energy use along with a pattern of consumption were to continue, it would become increasingly more difficult for individuals and countries to afford these resources.

The Arab Oil embargo made people and governments realize that something had to be done to reduce dependence on supplies of foreign oil and indeed the dependence on non-renewable energy resources. This period ushered in the emerging age of the scarcity of fossil fuels. Energy conservation and local self-reliance became new buzz words.

This period led governments and private industry to seek out new ways of producing energy. Engineers sought answers in the field of alternate, renewable, cost-effective and ecologically-sound energy sources such as the sun, wind and bio-fuels. And though on hold now, because of a slump in the economy and the temporary availability of cheap oil, energy concerns will inevitably come to the fore in the not too distant future.

Problems

The foregoing paragraphs illustrate the underlying assumption and basic problem that underlies the theme of this thesis, that of a potentially rapid depletion of nonrenewable energy resources. In essence, what can replace them in the world today, and in the future? Canada imports about 25% of its oil from OPEC nations and others. In the past the trend has seen foreign oil rise in price and this is expected to resume. For northern communities that depend upon diesel fuel for heating, this continual increase in prices makes it a hardship. And Canada cannot continue to expect that we will be able to import this fuel. An alternate fuel is thus much needed. In fact the National Energy Program has as its main aim the objective of reducing reliance on imported oil. [3]

Non-renewable energy resources were formed in the earth's crust many millions of years ago-coal, natural gas, oil and uranium. These resources were once thought to be limitless, but we now realize that they are being depleted at an alarming rate. Unfortunately it would take many millions of years to replace these resources. And as we have begun to project their rate of depletion we can well forsee their demise.

Renewable energy resources have been in existence almost since the world began. They include energy produced from the sun, wind, tides, water, biomass and geothermal heat. With the exception of hydro-electric power, these resources have not been developed to any great extent to extract their energy. So their cost-effectiveness and reliability have not been proven. However enough experimental data has been gathered and pilot projects undertaken to permit a sound estimate of their potential for replacing non-renewable (fossil fuels) energy resources.

The Government of Canada has placed an emphasis on the search for alternatives, first outlined in the National Energy Program and followed by the establishment of the Remote Community Demonstration Program (RCDP) under the auspices of Energy, Mines and Resources Canada. The program's aim is energy use and renewable energy alternatives in remote communities. Remote communities are described as those not connected to a main provincial grid or natural gas pipeline.

The following statement indicates the importance of RCDP to the government: [4]

> "Remote communities throughout Canada have very high energy expenditures compared with more accessible areas, and most of this energy is derived from oil. Besides the cost of oil and its transportation to remote locations, there is also the question of energy security, since there are usually fewer options and smaller margins of manoeuvre in these communities as regards alternatives to the supply, transportation and storage of oil products."

For example, in a study of 52 remote communities in the province of Quebec (communities ranged from 110 to 3500 people; total population - 38,330), 48 relied solely upon diesel fuel for their heating and electrical needs. [5] Options for replacing diesel fuel ranged from district heating systems, to active solar energy to peat. Feasibility of the alternate sources ranged from high to low depending upon the area where the community was located.

In Manitoba for example, sixty-six projects under the Small Scale Energy Demonstration Program were funded. Projects ranged from waste heat recovery experiments to wind energy. Major utilities, such as Ontario Hydro and Hydro Quebec, and the Canadian Electrical Association are becoming more involved in alternative generation. Table 1 on page 16 illustrates the present and future projections of alternate energy technologies and their applications. As is evident, cogeneration has by far the largest expected output, however wind has the greatest percentage increase of almost 900 %.

This thesis will examine the alternate energy resources available and using a case study to show that they can provide the energy required by a remote community. In effect an autonomously serviced community; ones that generates its own power and heat. The example to be used is Canadian Forces Station Gypsumville, a small Manitoban interlake settlement. However that is not to say that this discussion will be site specific. The principles and ultimately the energy systems available can be used over a wide range of territory, essentially the breadth of Canada; from the Yukon to Labrador. Figure 1 illustrates a generalized view of the area under consideration. The east-west lines represent the boundaries. Figures 2, 3, and 4 detail the existing transmission lines. In the area that has been outlined in Figure 1, there are many remote settlements and more importantly there is a lack of distribution systems able to supply them with Canadian gas and oil as the subsequent figures graphically illustrate.

ORIENTATION

Disciplinary Context

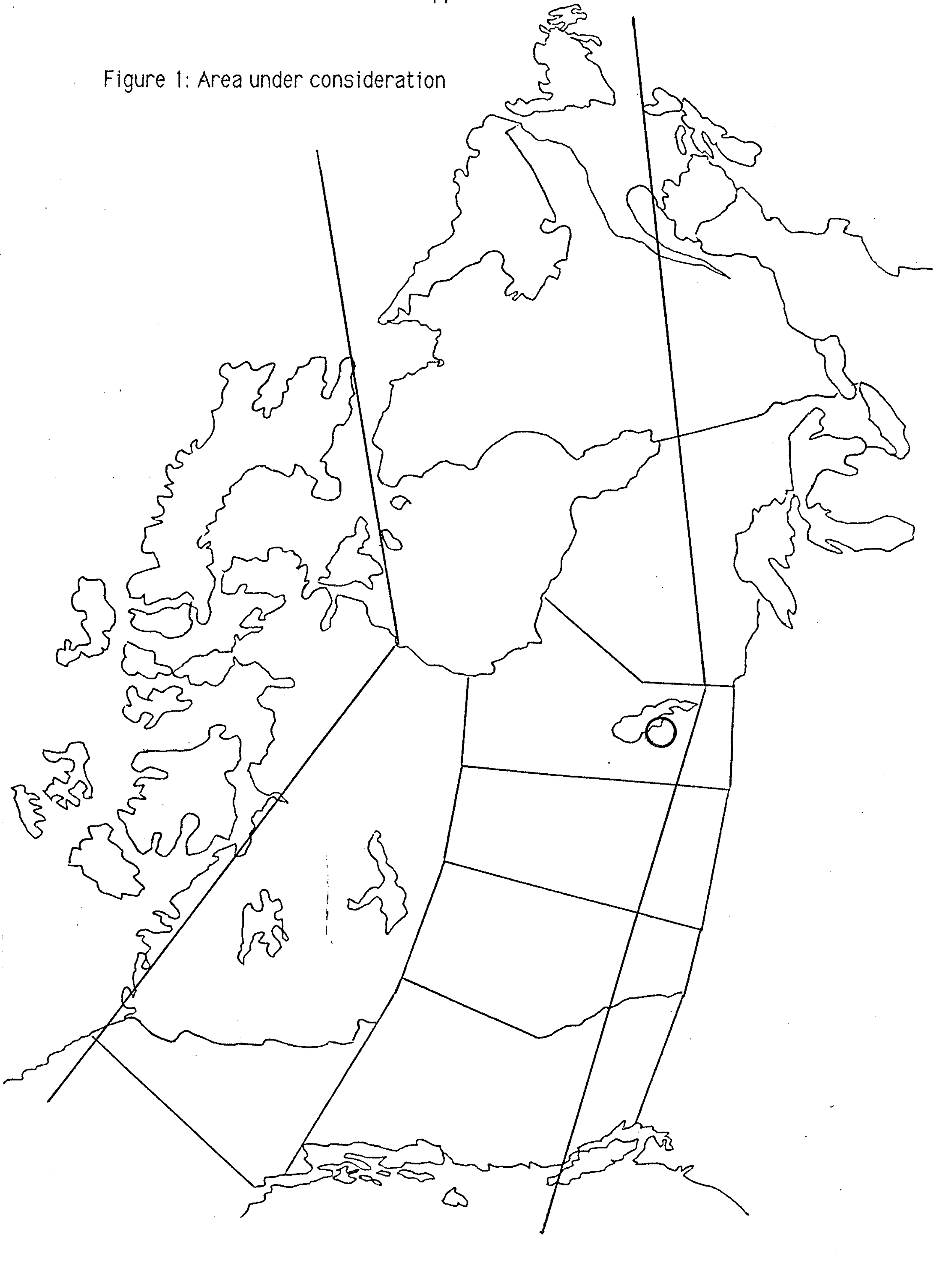
The thesis will be a planning study with an engineering bias and will relate to functional and spatial criteria necessitated by alternate energy systems.

Table 1 Canadian Alternative Energy Generation: (1985-1995)

Technology	Installations 1985 (actual)	Installations 1995 (expected)	Output (MW) 1985 (actual)	Output (MW) 1995 (expected)	Applications
Private Hydroelectric	200	400	882	1042	*Private and Municipal development *Remote community power
Wind	600	1000	6	50	*Small Scale independent systems *Remote community Power
Cogeneration (Incl biomass)	344	1000	1200	3500	*Industrial and Institutional
Municipal Solid Waste	5	15	4	15	*District Heating *Municipal and industrial
Photovoltaics	2100	4000	0.1	1	*Off grid, power applications *Remote community power

Source: Data provided by the Department of Energy, Mines and Resources (Canada), the provincial governments and major utilities across Canada.

Figure 1: Area under consideration



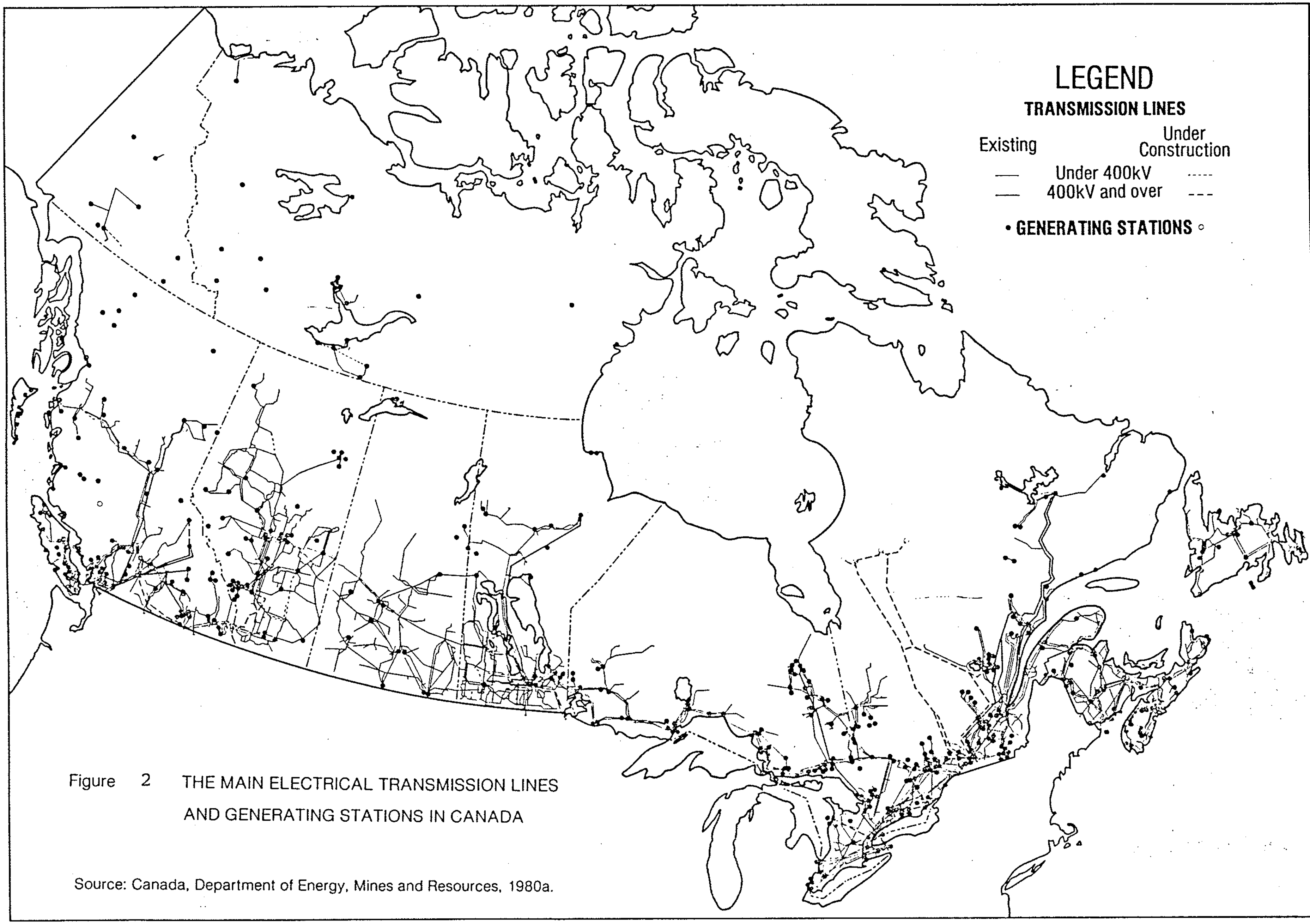


Figure 2 THE MAIN ELECTRICAL TRANSMISSION LINES AND GENERATING STATIONS IN CANADA

Source: Canada, Department of Energy, Mines and Resources, 1980a.

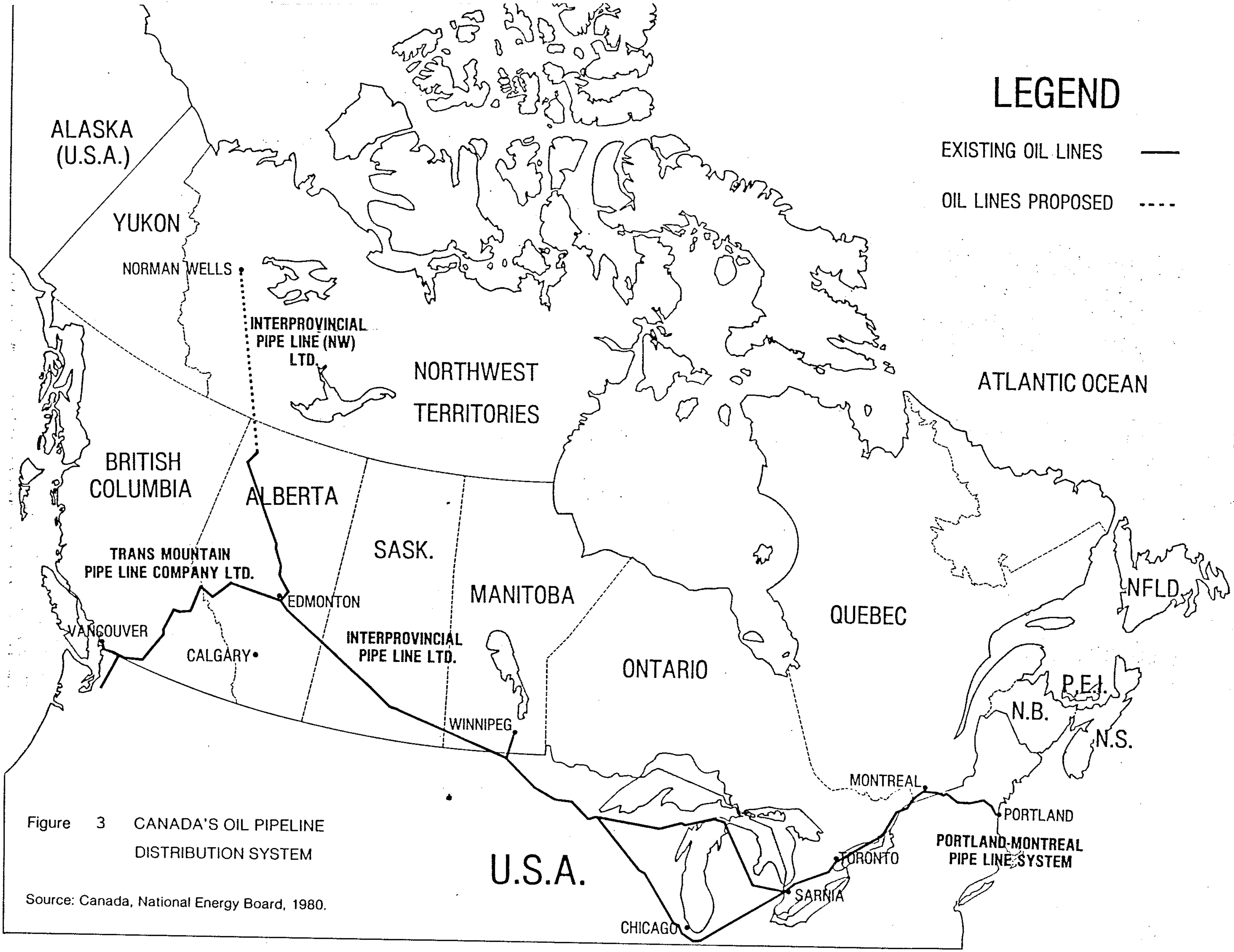


Figure 3 CANADA'S OIL PIPELINE DISTRIBUTION SYSTEM

Source: Canada, National Energy Board, 1980.

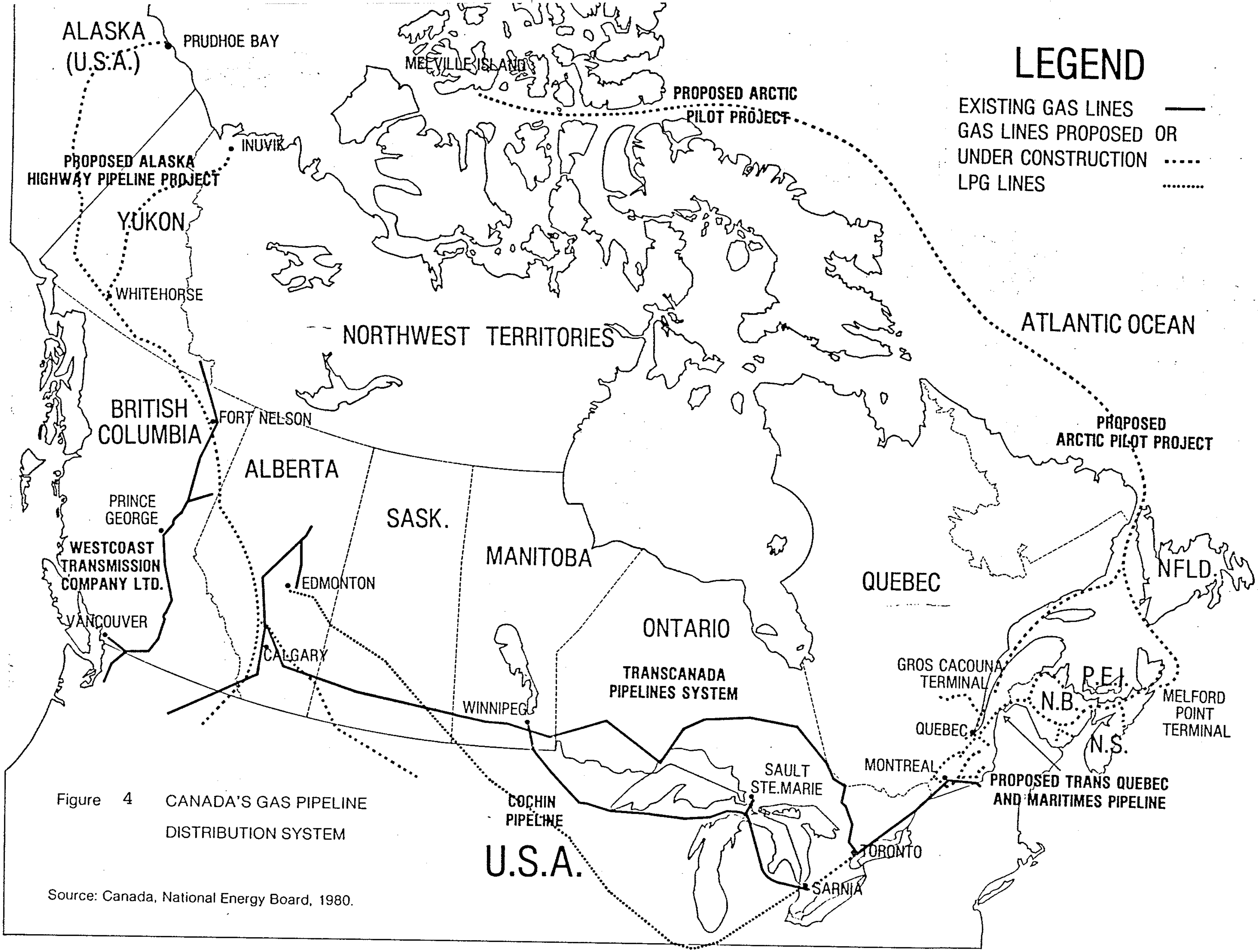


Figure 4 CANADA'S GAS PIPELINE DISTRIBUTION SYSTEM

Source: Canada, National Energy Board, 1980.

Viewpoint of the Writer

The writer is taking the viewpoint that the energy crisis is very real and that non-renewables are being depleted at an ever increasing rate. In this decade and the next the problem will get more acute and the search for viable and reasonably priced alternatives will quicken. This will eventually lead to the establishment of autonomously serviced settlements i. e. those small communities that produce their own energy (heat and electricity). It is the writer's opinion that this could be achieved now. It is realized that the energy crisis has been defused somewhat over the past several years but it has not totally disappeared.

Type of Thesis

This thesis can be characterized as an exploratory thesis complemented by an illustrative case study. The renewable energy resources will be described using the headings--history, principles and systems. In other words: How did each source develop; what are the basic principles under lying its physics and what is the state of the art today; and, how can it be used in our selected settlement?

Limitations

This thesis will not attempt to redesign the settlement or delve into the physics or detailed engineering aspects of alternate energy systems. It will limit itself to the systems that are commercially available now and those that have a good chance for success in the near future. The thesis will analyze only the requirements for heat and power, not those for water and sewage, food and transportation.

Nuclear energy will be included since the technology and fuel have been designed and built by and for Canadians. It is assumed to be a safe and reliable form of energy. Proven reserves of uranium are sufficient for the forseeable future and are available in Canada, they do not have to be imported. Also small reactors for northern communities are currently being investigated by various government departments, most notably Atomic Energy of Canada Limited (AECL) and Department of National Defence (DND). In addition several nations are interested in our small reactor.

Economics will be considered but only in general terms. The various systems will be costed and operating expenses compared to the existing power plants. General orders of magnitude will be discussed. This will be necessary due to the lack of accurate cost details because these systems are not widespread, some are in the pilot project stage while others are still in the preliminary stages of development, such as nuclear fusion. This is the situation due to the lack of emphasis on the development of alternate energy systems while the price of crude oil is low.

METHODOLOGY

Sources of Data

Data will be collected from all available sources: books, periodicals, textbooks, research reports, proceedings from energy conferences, manufacturers specifications, case studies; and, in the case of CFS Gypsumville--a site visit, personal knowledge and technical data from station records i.e. Facilities Catalogue and station personnel.

Research Methods

Starting from the basic premise of the autonomous community as presented in the article of E.A. Levin "The Autonomous Community: City of the Future?" [6], a library search of all the pertinent and relevant materialwas undertaken. Once the topic was refined to include only alternative energy sources, all the available energy sources were researched to find those most suitable. Included was the caveat that all sources had to be in production and available on the market. A suitable small settlement was then chosen to confirm that the basic premise was correct i.e. a case study analysis.

SUMMARY

The first chapter presents the aim of the thesis and outlines the steps that are to be followed to prove the hypothesis. It reviews the importance of energy and describes the problems caused by the Arab boycott and the diminishing reserves of fossil fuels. It concludes by proposing that alternate forms of energy are available today and they are suitably advanced technologically to replace fossil fuels as the energy sources for the future.

Chapter 2 begins by defining energy and describes why it is important. The energy provided by the various fossil fuels are outlined. The aims of the National Energy Board are presented. The various forms of alternate energy that have been identified as being replacements for fossil fuels are described. These alternate energy systems consist of solar power, wind power, nuclear energy, geothermal energy and biological (biomass) systems. Each energy resource will be detailed by outlining its historical development, its principles of operation and the systems available on the market today for converting each resource into two useable end products: electricity and heat. The chapter concludes by identifying the system(s) that will be appropriate for use in the Interlake region of Manitoba.

Chapter 3 describes the community that will be used as the case study for this thesis - Canadian Forces Station Gypsumville. Its location, climate and a description of the site will be presented. The site description will center on the different types of buildings and their unique energy problems and be limited to the two sites; the station area and the Married Quarter area. The heating and electrical systems will be then be detailed and the specific requirements to meet the heat and electrical loads will be outlined. This will be expanded to include the station as a whole. Gypsumville has been chosen as the case study since it is a typical isolated community and parallels those features found in many small mining towns, remote northern communities and Indian reservations. It is relatively isolated, its population is small, there is housing, an industrial area, a recreation complex and retail area. Factual data on the site characteristics are readily available and the station is accessible simplifying the collection of data. And most importantly, a model i.e. fictious community does not have to be created in order to prove the hypothesis. While electricity is supplied the station relies upon expensive heating oil and diesel fuel to provide the heating needs.

Chapter 4 outlines the various alternate energy systems that were described in Chapter 2 as being suitable for the case study analysis. The systems chosen will then be described in detail to show that they can provide the energy necessary to meet the specific electrical and heating needs of the Station. The advantages and disadvantages of each system are then documented. Economics will also be included in the analysis. The different methods of determining the most economical system will be presented along with the cost of each alternate energy source. The chapter concludes by recommending the system that is the most appropriate and feasible to provide the heating and electrical needs of the Station.

AUTONOMOUSLY SERVICED SETTLEMENTS

CHAPTER TWO

ALTERNATE SOURCES OF ENERGY

INTRODUCTION

This chapter will discuss the various modes of alternate energy that have been outlined in the previous chapter as those able to replace fossil fuels in the future. These renewables include solar energy, wind power, geothermal energy, biomass systems and nuclear energy. Each resource will be described under three main headings - history, principles and systems. This energy will be used to supply heat and electricity for CFS Gypsumville. But before each alternate energy system is described, energy itself must be defined.

ENERGY DEFINED

Energy is the lifeblood of all living things on earth. It pervades our very existence and effects our lives every minute of every day. From a position of unlimited, cheap supplies several decades ago we have pro- gressed to a point today where energy resources are being depleted at an ever increasing rate (this has slowed somewhat due to the efforts of conservation). Coupled with the increase in population to some 6 billion by the year 2000, our ability to meet the rising demand for energy will be strained as time inexorably goes by.

Energy is defined as the ability to do work. It is controlled by the laws of physics, these being the laws of thermodynamics. The basic unit of energy is the joule (in the SI, Systeme International, nomenclature) which can be used for all forms of energy. Concurrently, power is the other half of the equation; it is defined as the rate at which energy is converted. The common unit here is the watt. Therefore: Energy = Power x Time; i.e. one watt equates into the delivery of one joule in one second.

Energy can be quantified in many different forms--tons of coal, cubic feet of natural gas, kilowatt-hours of electricity, barrels of oil-- depending upon what source of energy is utilized. A unit of measurement, the "quad" has been devised to simplify the measurement of energy on a large scale. Using this measurement enables the quantifying of present and future sources of energy in easily understandable and manageable terms.

A quad is defined as one quadrillon Btus (1×10^{15}) where Btus (British Thermal Unit) is the English measurement that represents the quantity of heat required to raise the temperature of one pound of water by one degree Fahrenheit. In the S.I. system, the Btu is replaced by its equivalent of 1,054 joules. Then one quad becomes 1.054×10^{15} joules; which means that the various forms of energy are equivalent and therefore all can be equated to joules. Table 2 illustrates the quantities of various energy sources equivalent to one quad of energy. [7]

Table 2: Equivalent Quantities of Energy Sources for 1 Quad

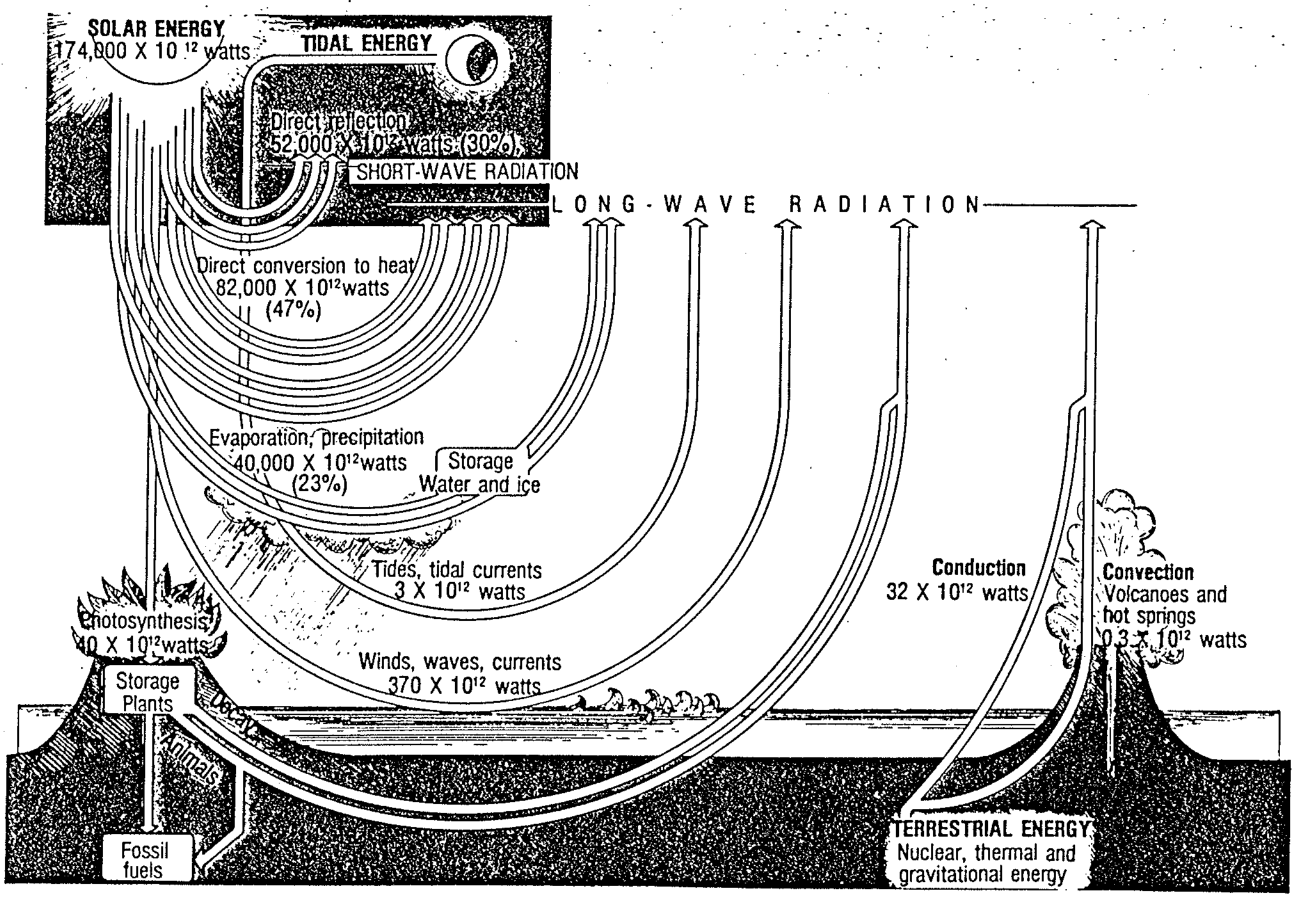
Energy Source	Units of Measurement S.I.	Imperial
Petroleum	29×10^6 m^3	1.8×10^8 barrels
Coal	42×10^6 metric tons	4.6×10^7 short tons
Natural Gas	28×10^9 m^3	10^{13} standard ft^3
Uranium	4.6×10^{-4} metric ton	5×10^{-4} short tons
Electricity (thermal)	300×10^9 kilowatthours	
Electricity	100×10^9 kilowatthours	

Source: Handbook of Energy & Economics, 1983, pg 2.

Energy is totally derived from the sun. The amount of solar energy received at the outer boundaries of the earth's atmosphere (radiation in the form of visible light @ 47% and infra red (heat) 46%) is immense, in the order of 180,000 TW(1 TerraWatt=10^{12}Watts). A majority of this energy is reflected and reradiated into space before it can be used, 62,000 TW and 76,000 TW respectively. Evaporation consumes another 40,000 TW.[8] The amount that is left exceeds by 500 times that which is produced by the world's generating capability. Figure 5 shows the overall power flows in this process.

Presently oil, natural gas, coal, and uranium provide fuel for 94 % of the world's energy production, nearly 297 quads per year.[9] This

Figure 5: The Earth's Energy Budget



Source: After Hubbert, 1974, p. 11.

rate of usuage would deplete the world's proven potentially recoverable reserves, 24,000 quads, within about 80 years. Furthermore, oil supplies 134 quads per year, which at present consumption rates would last only 30 years based on estimated potential recoverable reserves and 7 years based on estimated proven recoverable reserves.[10] Table 3 compares the energy consumption of Canada and the United States with that of the world.[11]

Table 3 Primary Energy Consumption 1983 (Quads)

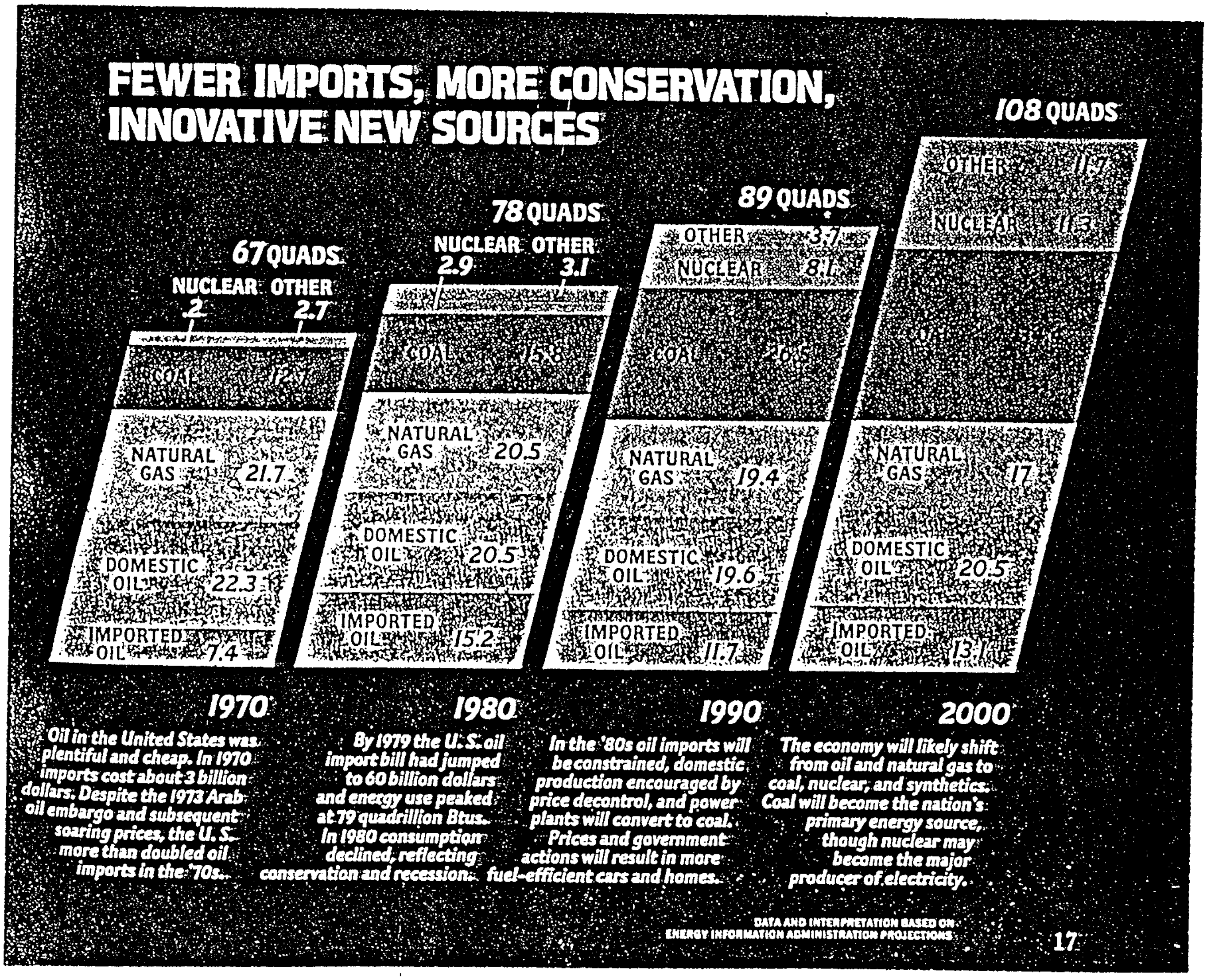
	Nat'l Gas	Oil	Coal	Hydro	Nuclear	Total
USA	17.5	28.4	16.2	3.87	3.24	69.28
CDA	1.9	2.7	1.14	2.26	.97	8.46
WORLD	53.9	113	85.0	19.02	9.58	280.7

Source: BP Review of World Gas Aug 84

Table 4 shows, for the United States, how their energy balance and consumption will change over the years (1980 data).

Canada is in a rather enviable position, that of being a net exporter of energy. On the plus side we have abundant supplies of natural gas and hydro-electric power, an efficient and relatively safe nuclear energy system, and a good supply of coal. However we are also an importer, about 25% of our oil consumption, in one of the most important energy sources - - crude oil. Atlantic Canada depends upon this expensive oil for the generation of electricity. The lack of distribution systems prevents this region from receiving domestic

TABLE 4



Source: National Geographic A Special Report: Energy, Feb 1981 pg 17.

supplies of oil and natural gas.

Canada is not exempt from the effects of the policies of OPEC (Organization of Petroleum Exporting Countries). OPEC is still an entity to be reckoned with and they may be expected to exert considerable influence for the forseable future. To reduce and eliminate this threat Canada must reduce its dependence on foreign supplies of oil. The Government of Canada recognized that it needed to act and, in 1980, established the The National Energy Program. The Program had three main aims, with the most important being-- [12]

> "to seize control of our energy future through security of supply and ultimate independence from the world oil market."

To this end three ways have been established to achieve oil independence: (1) development of domestic oil supplies, (2) reduced consumption of oil products, and (3) rapid substitution from oil to more plentiful Canadian energy sources. [13] This thesis concentrates on the third course of action.

This course of action will be implemented by turning to alternate sources of energy. These sources will primarily be renewable rather than non-renewable: it doesn't make sense to spend millions developing an energy source only to have it depleted after a number of years. This energy is looked upon as more than just alternate energy: [14]

> "conceptually, the beauty of alternate energy has not been merely its efficiency and its diminution of pollutants, but the ecological interaction of solar collectors, wind generators and methane digesters with each other and with many other sources of energy, including wood, water and yes, coal and petroleum where necessary--to produce a new energy pattern, one that is artistically tailored to the ecosystem in which it is located."

This has a highly simplistic view of the future but in many instances it approaches the basic truth.

Several definitions are in order as some of the phrases are similar but have different meanings. [15]

Energy Self-Reliance	To meet energy demands from domestic sources to such an extent that no serious dislocation would occur if external energy sources were eliminated.
Inexhaustibles	Energy sources which are virtually infinite in terms of their utilization in the forseeable future, or which are replenishable. Includes the renewables: fission breeders and fusion nuclear energy.
Renewables	Energy sources which are perpetual or replenishable; have life spans comparable to that of the solar system. Solar, biomass, geothermal, wind and hydraulic--river, ocean tides and waves are examples.

Resource	All potential energy-producing natural phenomenon and accumulations of naturally occuring substances which are known to exist (eg. oil, natural gas, coal, uranium, hydraulic peat and forest biomass).
Non-Renewables	Those energy resources that are depleted by use.
Remote Communities	Those communities not connected to a main provincial hydro grid or natural gas pipeline.
Autonomously serviced Settlements	Those communities that produce their own power.

It is generally acknowledged that there are two paths towards meeting the world's energy requirements; the soft and hard paths. The hard energy path is characterized by a centralized, high energy, nuclear and electricity-dependent path. [16] The hard path uses non-renewable energy sources, e.g. coal and nuclear fission for generation of electricity, and other sources such as oil and gasoline for transportation. Whereas the soft energy path is characterized by a decentralized, lower energy and nuclear free path. Alternate forms of energy, solar, wind and biomass, are to be used to generate electricity. These energy sources are said to be benign and pollution free, more suitable for local communities, than the polluting non-renewables headed by coal and nuclear fission.

An aspect of this theme that has not been discussed is energy conservation. One can argue that it is, in its own right an alternate energy source. In the past many of our activities have been wasteful and inefficient brought on by cheap energy of the 50's and 60's. The trend has been reversing since the oil crisis of the early 80's. The importance of this reversal can be seen by examining energy consumption figures of R2000 houses over the standard of the late 70's; they are between 40 and 80 % lower. Alternately many industries are turning to co-generation i.e. the simultaneous production of heat and electricity. Most of these measures can be done for relatively modest cost resulting in a short payback period.

Energy conservation should be the first step in any move to alternate energy sources. In essence, the less energy used the smaller will be the total energy conversion system and the lower the overall cost of the system and the energy it produces.. Energy conservation methods and techniques can be relatively simple to implement; better insulated and air-tight houses, more efficient appliances and furnaces, proper lot orientation to increase passive heating and material recycling.

The Special Committee of the House of Commons on Alternate Energy and Oil Substitution in its report concluded that Canada's energy system will be a mix of hard and soft technologies combined with a blend of centralized and decentralized sources as far as they can see into the future. [17] This thesis is falling into line with the Committee's recommendation: i.e. that the possible energy sources are going to be renewables along with nuclear energy, natural gas and hydro-electric power.

SOLAR ENERGY

Introduction

The sun is the most prominent and powerful energy source known in our solar system. It pervades all life on earth and in fact was the prime catalyst for the evolution of life as we know it today. Many energy resources owe their existence to solar energy including fossil fuels, wind and water power, and biomass. Solar radiation is the means by which the sun's energy can be transformed into thermal energy for useful purposes. Its energy content, in the form of radiation is awesome. The amount of energy that irradiates Canada is 500 times more than is produced by the aggregate of all our current generating capacity.

Solar energy is a very valuable resource in that it is available everywhere, is non-polluting and it is truly abundant and renewable. Its drawbacks include the fact that it is time and location dependent.

The problem, then is how to utilize this energy. In its simplest form, the necessary system components include collection, storage, distribution and control.

History

The earliest attempts to utilize solar energy can be traced far back into the history of mankind some 2100 years ago. The first historical accounts of the deliberate use of the sun's energy describe the use of mirrors and lenses to burn or melt various metals or act as simple water pumps. Specific references to this use date from 1000 A.D. However it wasn't until the mid 1850's that the first machines were designed to make practical use of the sun on a much wider scale than previous attempts. This was accomplished by two French scientists, Deliancourt and Mouchot, and an American, Ericsson with the construction of solar thermal engines. In 1912 a 40-kw parabolic reflector-steam engine system was used in Egypt to pump irrigation water from the Nile. [18]

Modern research into the use of solar energy for heating can be traced back to the work originally done by the Massachusetts Institute of Technology in the late 1930's. [19] Subsequently this start resulted in the development of several solar heated structures in the Boston area that provided up to 70% of the total heating loads. In the years that followed many designs and applications were investigated. Several residential houses, that have been specifically built in the 60's to illustrate the differing designs of solar heating systems and to determine collector efficiencies, are based on the two basic working fluids-water and air. [20] Those systems having air as the working fluid use pebble-bed storage whereas water systems use water storage tanks.

It wasn't until the Arab oil embargo of the early 70's that serious research was undertaken. In 1971 Surrey B.C. was the location of the first Canadian built and designed solar house. [21] Now there are a myriad of structures utilizing solar heat for both heating and cooling and several industrial applications.

Today there are many applications involving the conversion of solar energy into useful work. Technologies pertinent to this thesis include: [22]

1. Passive heating of buildings;
2. Low level heat used for
   a. space heating
   b. water heating; and
3. Direct production of electricity from photovoltaic cells.

Principles

The sun is a sphere of intensely hot gaseous matter; in effect it is a continuous fusion reactor converting hydrogen into helium. The resultant release of energy is radiated into space; a very small portion of this radiation eventually falls on earth where it can be utilized. The incident solar radiation is transmitted through the atmosphere where it is in part absorbed and part scattered by components of the atmosphere (scattering by air molecules, water vapour and dust, and absorption by O_3, H_2O and CO_2).[23] For most solar energy applications only thermal (electro- magnetic) radiation is important.

Solar radiation is also a function of sky conditions-cloudiness and atmospheric clarity-both of which are highly variable. Total energy also varies on a monthly, seasonal or annual basis. Incident radiation can be increased by sloping a solar energy collector. From many studies over the years a general rule of thumb can be stated:[24]

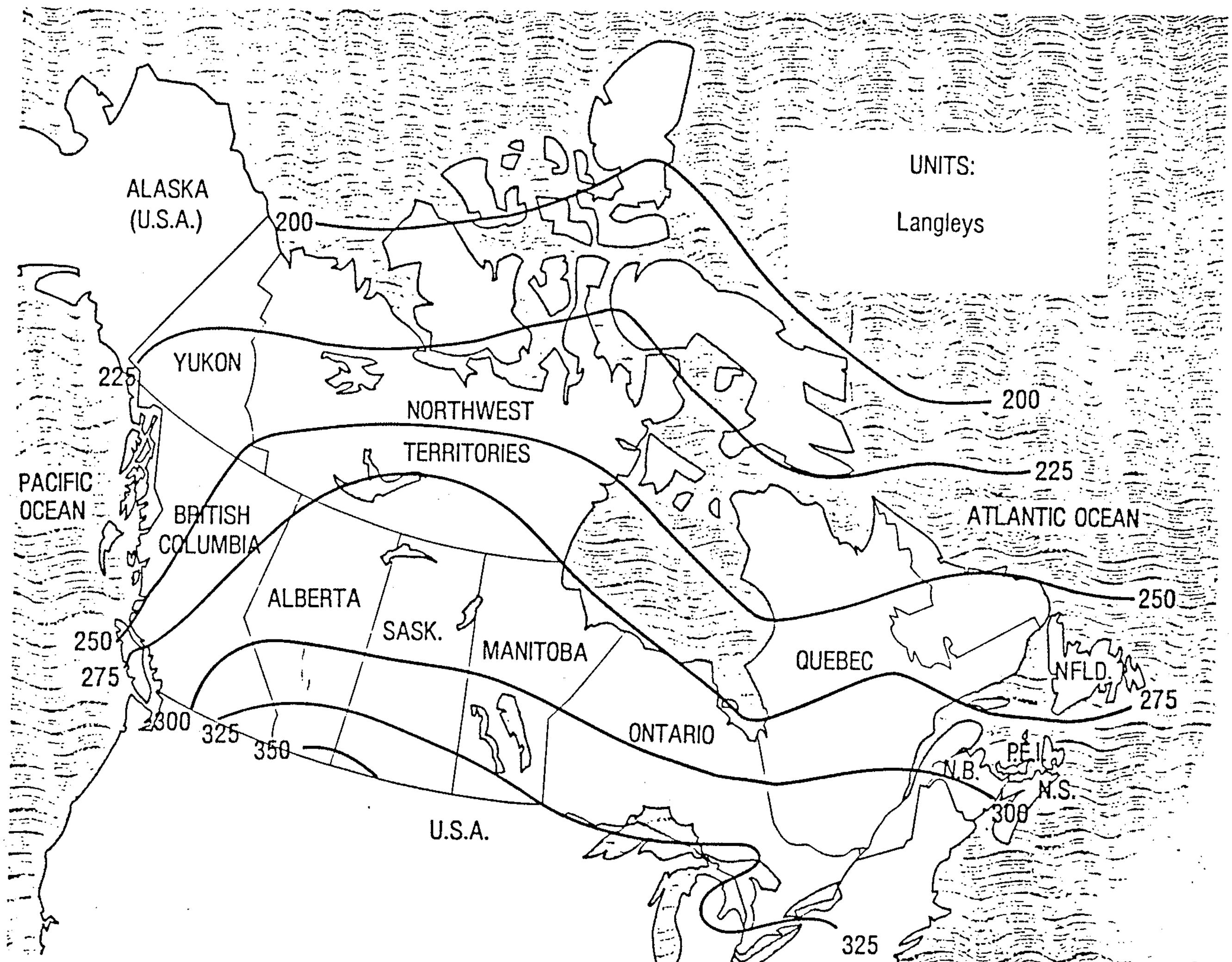
> "For maximum annual energy availability, a surface slope equal to latitude is best. For maximum summer availability, slope should be approximately 10' to 15' less than the latitude. For maximum winter availability, slope should be 10' to 15' more than the latitude."

The slopes are not critical; deviations result in a reduction of the order of 5%. Reflective ground cover, such as snow leads to higher slopes for maximizing winter energy availability.

The intensity of solar energy varies with time and location, specified by the longitude and latitude. This fact is especially significant at high latitudes such as Winnipeg where the major use of this energy is in the winter when it receives the lowest radiation. Figure 6 illustrates the mean daily solar radiation in Canada. Two cycles [25] come into play - the diurnal or daily cycle, and the annual cycle. In the diurnal cycle the intensity of the solar radiation varies

Figure 6: Mean Daily Solar Radiation in Canada, Measured on a Horizontal Surface and Averaged Over The Year.

NOTE: The units on the map are Langleys, a Langley (ly) is a unit used primarily by meteorologists. A Langley is equivalent to 11.6 watthours/sq meter/day. Solar power, or solar radiation intensity, can be expressed as Ly/day.



Source: Canada, Department of Energy, Mines and Resources, 1980d.

from 0 at night to a mid-day maximum that may be two and one half to six times the daily average. For example in the dead of winter the daily total radiation is received in only four hours whereas in mid July useful energy is received for well over 10 hours. For northern climates the annual cycle provides a most serious obstacle.

There is a wide variance in the daily average radiation received between winter and summer. In winter the low elevation of the sun is the primary reason for the low radiation received on a horizontal surface. This fact can be overcome by tilting the collector towards the sun at an appropriate angle. A south facing fixed collector collects radiation for a period of time but will also loose some at another period of time. The solution to this problem is to incorporate a tracking collector to absorb the maximum amount of energy at all times. In northern latitudes tracking does not accrue enough benefits for it to be feasible.

Systems

There are two methods of utilizing solar energy for space heating: (a) passive systems (natural) ; and, (b) active systems (engineered) . Active systems use collectors to heat a fluid, storage units to store energy until needed, and distribution equipment to provide the solar energy to the heated spaces in a controlled manner. The collectors and storage units are separated in order that the losses from the collector do not occur when the collector does not operate and that losses from storage can be controlled by insulation. Passive systems depend on the same principles as active systems except that the collectors and storage units are integrated into the building structure and often depend on movable insulation and glass surface area to control thermal losses. The various components of solar heating systems are shown in Table 5.

Passive Systems

Passive systems are similar to active systems but as their name implies involve no moving parts and are usually integral with the building structure - windows, walls and floors. Natural heat flow processes - radiation, convection and conduction - transfer the energy for space heating as opposed to mechanical means for active systems. Generally three systems for passive heating have been identified: direct gain; indirect gain or collector-storage wall, sometimes referred to as a "Trombe" wall; and, isolated gain or "sunspace". [26]

In direct gain solar energy is admitted directly through a south facing glass window, usually double or triple pane glass, falling onto the floor or walls that act as thermal energy storage. The resultant heat, in the form of longwave radiation is then distributed by convection and conduction. An overhang reduces the summer radiation to prevent overheating but allows the full winter sun to penetrate the

Table 5 Components of Solar Heating Systems

Solar Collectors	Convert solar insolation to another form of energy, which can be used for heating purposes (Space heating, domestic hot water, storage).
Energy Storage System	The energy not immediately needed for space heating is stored in this system to be used during periods without adequate solar penetration.
Air-Handler	Distributes the heated air through the building. The unit provides the mounting space for heat-exchangers, filters, humidifier, and supplementary heating system.
Heat-Exchangers	Transfer heat from one medium to another.
Pumps and/or Blowers	Supply the pressure to circulate the transfer media through the pipelines, ducts and the building.
Expansion tank with vent	Absorbs pressure changes in the loop, caused by different expansion coefficients of the tubing and the fluid in the lines. The vent protects the loop against damage caused by too high internal pressure.
Valves and Controls	Are essential for the operation of the system. The output of thermostats and sensors, placed in strategical locations, is used to switch from one operational phase to another.
Domestic Hot-Water Heater	Supplies a part of the required hot-water used for domestic purposes. This unit is most of time operational.

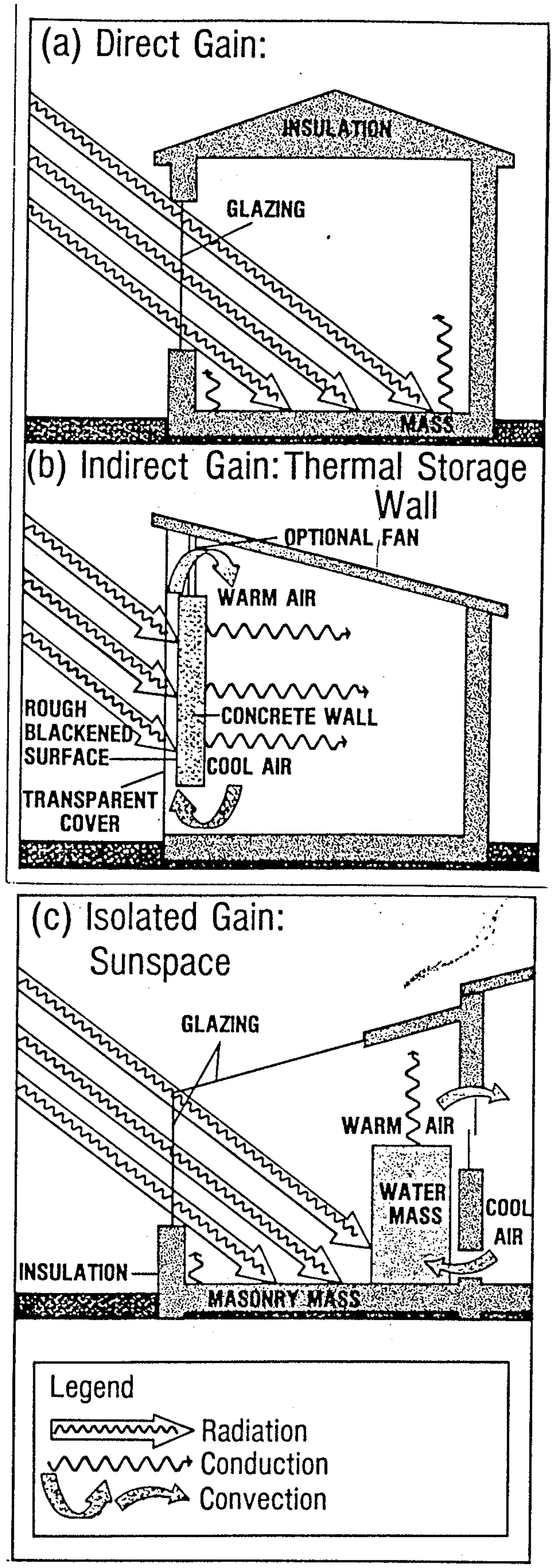
Source: Data collected/compiled from readings on Solar Energy structure. Moveable shutters or blinds prevent heat escaping during the night. However there must be some means to circulate the heat to other parts of the structure that do not have south facing windows. In essence the window and the room are a vertical south-facing flat-plate collector with thermal capacitance.

An indirect gain system employs a solar collector in the form of a massive wall that is placed in between the sun and the space to be heated. Energy is stored in this wall and is distributed by radiation and convection. Thermosyphoning is responsible for the movement of air around the exterior of the wall. Vents with dampers are used to permit the movement of cool and warm air. The walls can be made of either concrete block or drums and/or tubes of water. These walls are called "Trombe" walls after the French inventor of the same name.

A third method is the convective loop system or isolated gain thermosyphon system. By this method an angled solar collector heats a fluid, either air or water and, by a thermosyphoning loop, allows it to rise to a thermal store located above the collector. This system is similar to an active hot water system. Thermal storage, usually rocks, is normally located beneath the space to be heated. The convective loop principle requires that the solar collector also be below the storage area. Each part of the system must be properly designed to ensure the system functions properly.

A sunspace or solar greenhouse is another method of capturing the sun's energy. These spaces can either be added onto existing

Figure 7: Approaches to Passive Solar Heating



Source: After Anderson and Riordan, 1976, p. 14, 121, 234.

structures or integral into new house designs. This method is an adaption of the Trombe wall system. In this instance the air space is expanded to form a greenhouse. Thermal storage is accomplished by rock beds, concrete walls and/or floors, and water containers. The flow of warm and cool air is the same for the Trombe wall. Greenhouses are located on a south-facing wall with the usual energy conservation features as double glazed windows and insulation on the common walls. Forced air circulation can be added to improve the efficiency of the system.

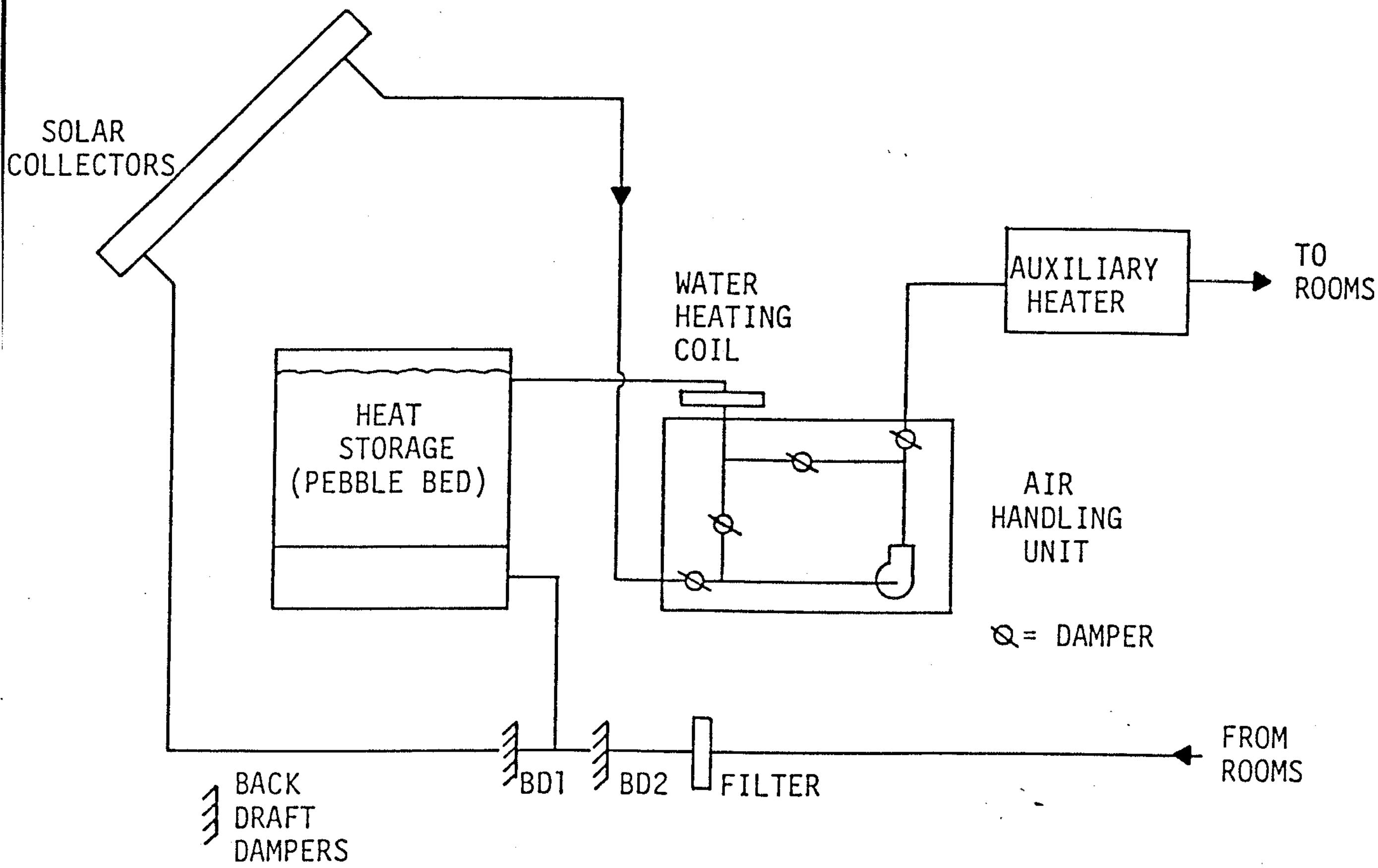
In cold climates energy losses can exceed the absorbed energy so care must be taken to ensure that the system is designed properly. The space should be narrow enough to allow the sun to reach the back wall. Figure 7 illustrates the above methods of passive solar energy systems.

Active Systems

Active systems use mechanical means-pumps and motors-to regulate and transfer heat to the structure. In this case the structure is not used for heat storage. A typical active system comprises the following components:- flat plate collector, a circulating loop to carry the heat from the collector to the building, a heat storage unit to assure that the heat can be distributed throughout the day and night, and a thermostat to control the distribution of heat when required. Figure 8 depicts a typical air-based active space heating system and Figure 9 shows a liquid-based system.

The incident solar energy that falls on the collector is delivered, via a working fluid (air, water or water-antifreeze mixture) to the heat storage unit through the heat exchanger. The collector and the heat storage unit are the most important components of the system. There are generally three types of collector - flat plate collector, parabolic concentrator and evacuated-tube. Flat plate is the most common collector. The parabolic concentrator is less widely used and can either be a tracking collector, used primarily for generation of electricity, and non-tracking for low grade heating. The evacuated tube collector can be used in place of a flat-plate collector but is more expensive. This is offset by its higher collection efficiency, especially at low temperatures. The size of the collector will generally determine what the system is used for.

The storage unit is the next most important component of the active system. The storage medium should have a high specifac heat to minimize its volume. It should be well insulated and be located in the structure that is to be heated. For systems that use air as the working fluid, rock-bed storage units are used (crushed rocks or rocks usually the size of golfballs). For systems that use liquids, water is probably the most cost-effective storage medium. Several new



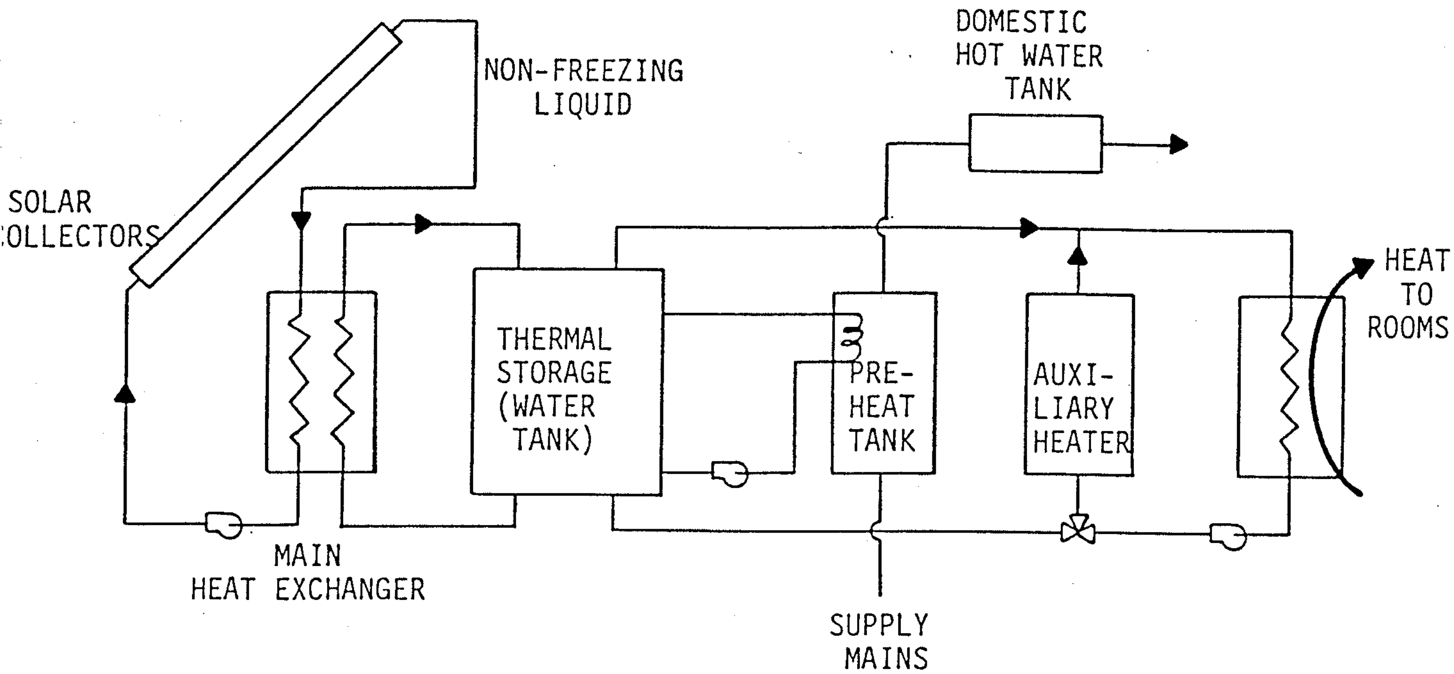
OPERATION: Hot air from the collectors is drawn through the air handling unit which uses four dampers to supply heat to the rooms or charge the storage. Energy is extracted from the storage by reversing the air flow through the pebble bed thus maintaining thermal stratification. A water heating coil is used to preheat the domestic hot water.

Source: Prospects for Solar and Wind Energy Utilization in Alberta, 1978

Figure 8

AIR BASED RESIDENTIAL

SPACE HEATING SYSTEM



OPERATION: Heat absorbed by the solar collectors is transferred to the thermal storage through the main heat exchanger which separates the antifreeze solution in the collectors from the storage water. Energy is extracted from the storage as required to maintain room temperature with any additional heat being supplied by the auxiliary heater. A preheating system for the domestic hot water tank is also usually included.

Source: Prospects for Solar and Wind Energy Utilization in Alberta, 1978.

Figure 9

LIQUID BASED RESIDENTIAL

SPACE HEATING SYSTEM

substances, Glauber's salts and paraffin waxes, are interesting developments in storage materials. This system uses chemical energy of products in a reversible chemical reaction; in other words they undergo a phase change. When this change occurs they release a large amount of latent heat per unit volume. The former uses the sensible heat of liquids or solids.[27,28]

The next components of the system, distribution units such as pumps and fans, thermostatic controls and auxiliary energy sources, are not peculiar to active solar heating systems but are used in many familiar situations in industry and residential units. In this regard individual features will not be addressed as they will be different depending upon the active system chosen and its particular application.

Hot Water Heating

Solar hot water heating can be accomplished by basically two means: (1) natural thermosyphon system; and, (2) mechanical heat distribution. The thermosyphon system is based on the passive approach using a convective loop. In this system the water storage tank is placed above the solar collector, most likely in the attic. The collector heats the water causing it to become less dense, then this hot water rises up into the storage tank replacing the cold water. The cold water then moves down into the collector where it is heated and the cycle continues i.e. convective loop.

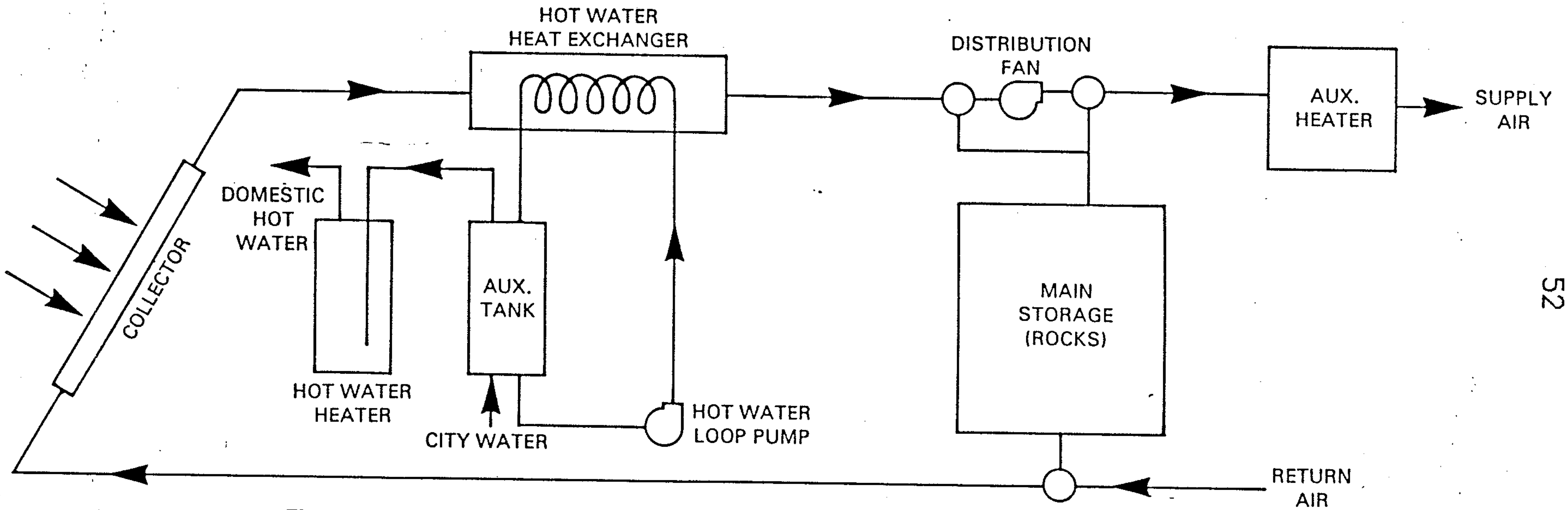


***Figure* 10 — Schematic of Air-Based Solar Space and Domestic Water Heating System**

Source: Prospects for Solar and Wind Energy Utilization in Alberta, December 1978.

Mechanical heat distribution is in reality an active system that contains a collector, energy storage system, energy distribution system, controls and an auxiliary heat source. The heat transfer medium is usually water or air. For an air system rock-bin storage is used; for a liquid system a thermal water storage tank is used. Figure 10 details a typical solar system. Basically, part of the incident solar radiation on the collector is transferred to the storage tank through the heat exchanger via the heat transfer medium. The resultant hot water heats the water in the water tank (where it can be distributed as required) and is returned through the system thus completing the loop.

A typical hot water heating load for a single family dwelling on the prairies is approximately 16 GJ or 15. 2 M Btus per year. Depending upon its location, size and type of solar collector used, this system would provide anywhere from 35 % to 75 % of the annual water heating load.

Direct Production of Electricity from Photovoltaic Cells

History

The solar cell effect was first postulated by the French scientist, Becquerel in 1839. However it was not until 1954 that the first device was invented--a 6% efficient solar cell by American scientists at Bell laboratories.[29] The major use of the cell and indeed its impetus for development was the American space program. Typical uses today include navigational buoys, microwave, radio and TV signal relay stations, unmanned offshore platforms and several thousand experimental houses (mostly in the US). Unfortunately its high cost has and continues to impede its widespread use (other than in remote areas and in the space and satellite programs).

The problem involves the necessity to produce high purity silicon cells; this process being energy intensive. Other methods of producing silicon cells are being investigated as well as the use of other materials such as gallium arsenide--more expensive but higher efficiencies--and cadmium sulfide (CdS)--lower cost but lower efficiency and reduced life. However the overall concept works very well; therefore research is concentrated on reducing the cost of producing solar cells.

Principles

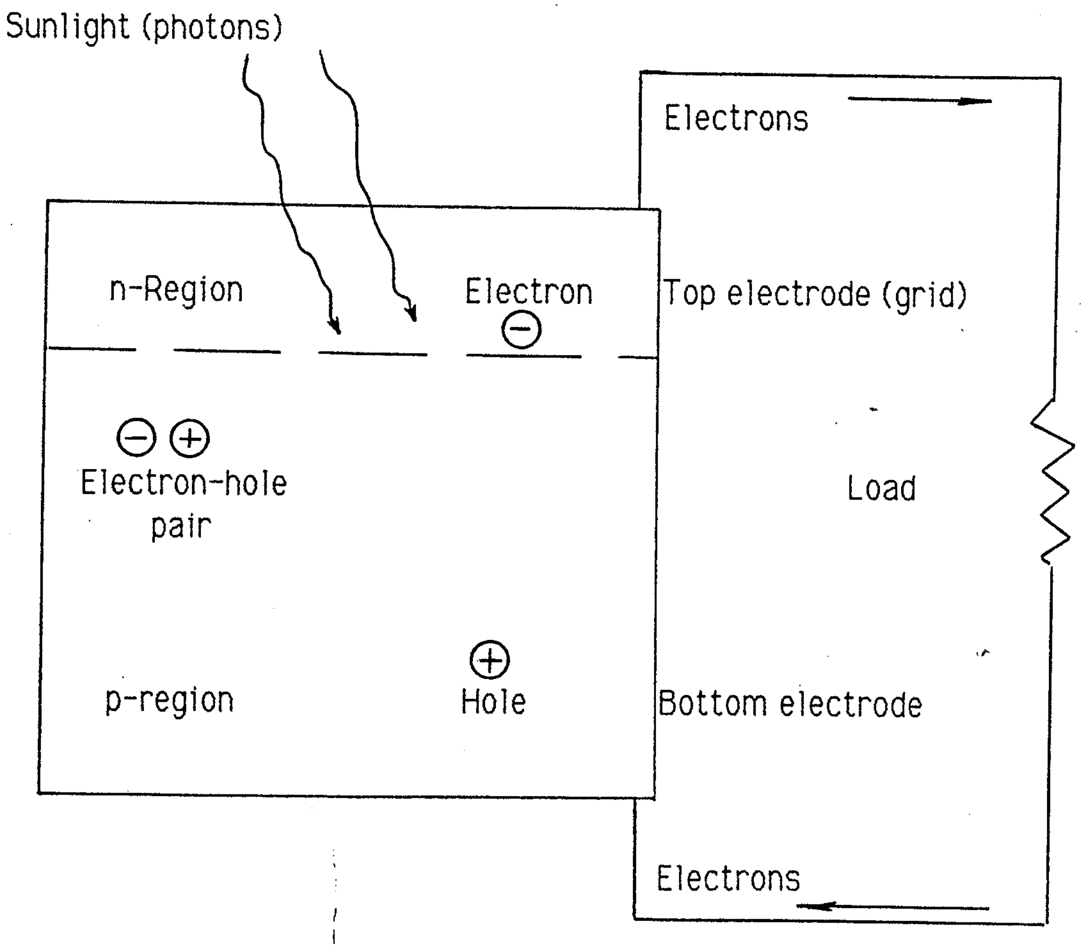
The operation of a photovoltaic cell (PV) is quite simple; photons (the sun's light) fall upon the junction of a semi-conductor thereby generating electricity. This cell has distinct advantages: it has no moving parts, consumes no fuel, produces no pollution during operation and can be made out of one of the most abundant elements on earth--silicon. In fact their power range can be from microwatts to megawatts depending upon the application. Figure 11 shows the basic operation of a solar cell.

This device has to do three things for it to be able to produce electricity from the sun:[31] (1) the cell must absorb a large fraction of the sunlight incident upon it and in turn use the absorbed energy to generate electron-hole pairs (negative-positive charges) within the bulk of the cell material; (2) the cell must have some means of keeping the newly created charges separated (i.e. prevent recombination), such as a built-in electric field (due to a p-n junction, Schottky barrier, etc.); and (3) the separated charge carriers must be free (have high mobility) to move through the cell to the electrodes (and hence the external circuit) without recombining or being trapped by a defect and/or impurity center. Figure 12 details the components of the two types of photovoltaic energy systems.

Systems

The two methods of solar electric generation available today are: (1) fixed flat-plate collector; and, (2) solar concentrators.[32] The fixed flat-plate collector has been extensively developed and is widely used, in addition to being the simpler generating system. Basically it is an array of silicon cells that convert solar radiation into electricity. This energy

Figure 11: Schematic diagram of basic p-n junction solar cell operation.



Source: After "The Sun on a Conductor"' 1978, p. 23.

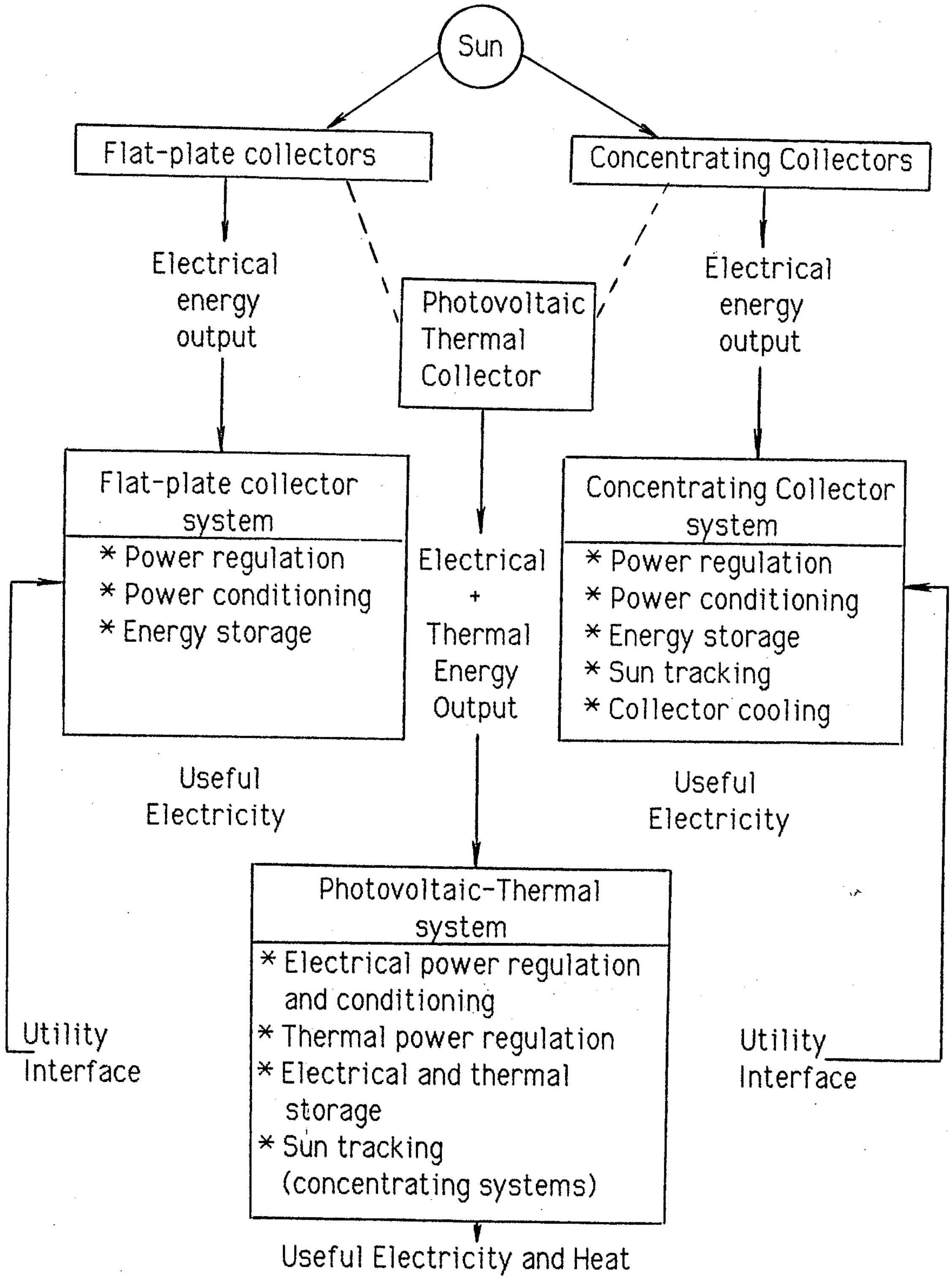


Figure 12: Block diagram showing basic photovoltaic energy system.
Source: Handbook of Energy Technology & Economics, Robert A. Meyers, 1983, pg 664.

would be used for residential homes and for small businesses. Solar concentrators, as their name implies, use mirrored reflectors or heliostat arrays to concentrate the sun's rays on high performance photovoltaic cells. This concentration allows the cells to be operated at a higher power density thus reducing the overall cell area. The reduction in cell area may be offset by the increase in cost of providing tracking devices and cooling apparatus. This energy would be generated at large utility power plants. For an example of what can be done with solar, a solar thermal electric conversion (STEC) scheme at Barstow, California involves a central boiler heated by sunlight from an array of heliostats (reflectors). This 10 MW(e) plant uses 1800 heliostats, each with 40 m^2 area, and incorporates 3-4 hours of thermal energy heat storage in rock. [33]

Typically photovoltaic power costs between $7 to $20 per peak watt installed. [34] Unfortunately peak power figures are misleading; the daily average output is the most useful figure, it being on the average 1/3 that of peak power. In most cases peak power is only produced during an hour or so at noon and, of course, only when the sun is shining. Then again not all energy applications are during the sunny hours of summer. In this case energy storage will be required--lead acid or nickel cadmium batteries.

One of the problems with this form of solar energy is that of size. Photovoltaics, by requiring continuous exposure to the sun, produce only 100-200 watts for every square meter of solar cell area. For an average house at least one half the roof area must be covered to produce enough energy. In comparison a conventional power plant, whether it is coal or nuclear, produces 6-8,000 watts per square meter of land.

Generally the components of the two systems discussed are the same as the components of solar space heating systems: collectors, in this case solar cells; an energy storage system; control and distribution mechanisms; and, unique power regulation equipment not needed previously. Power regulation equipment is required since PV produces power in the DC mode whereas 110/220 volt 60 Hz single-phase current is the electrical standard used today.

Conclusion

Photovoltaics are still too expensive to be used in most applications Costs have to be lowered by at least a power of ten to be viable with hydro-electric power in urban areas. Flat-plate collectors can be effectively used for the generation of electricity in remote areas especially where diesel generators are being used. In fact, several systems have been successfully installed in Northern Ontario. In the future, space-based large photovoltaic arrays (several kilometers square) would collect energy from the sun and transmit this power to earth using microwaves.

Solar energy can provide an alternate source for the production of heat energy, in the form of active and/or passive energy systems and for the generation of electricity by photovoltaics. It is possible to compare the costs of energy production for both systems but it must be remembered that one generates heat while the other produces electricity. Generally in urban areas costs for solar heat are on the average are 10 times greater than for natural gas while solar electric generation is 25 times that for conventional generation. Figure 43 page 179 illustrates aptly illustrates the gap between various alternate energy sources and those of conventional systems.

WIND POWER

Wind power was first used extensively, several centuries ago, in the Netherlands. The Dutch used it primarily to create the majority of their country by draining the Rhine delta with windmills. The advent of the Industrial Revolution steam power and the internal combustion engine brought about a severe decline in the use of wind power. However interest in this from of energy production has resurfaced due to the effects of the rapid rise in oil prices of the late 70's.

The source of the wind is the sun. Different areas of the world are heated by the sun to a greater or lesser extent than other areas. The physical motion of the air from the cooler areas to warmer areas is termed wind. Air has mass so its motion impacting upon a surface creates its transformation into mechanical energy. The problem then is to harness this mechanical energy and turn it into useful work in a manner that can be commercially viable.

History

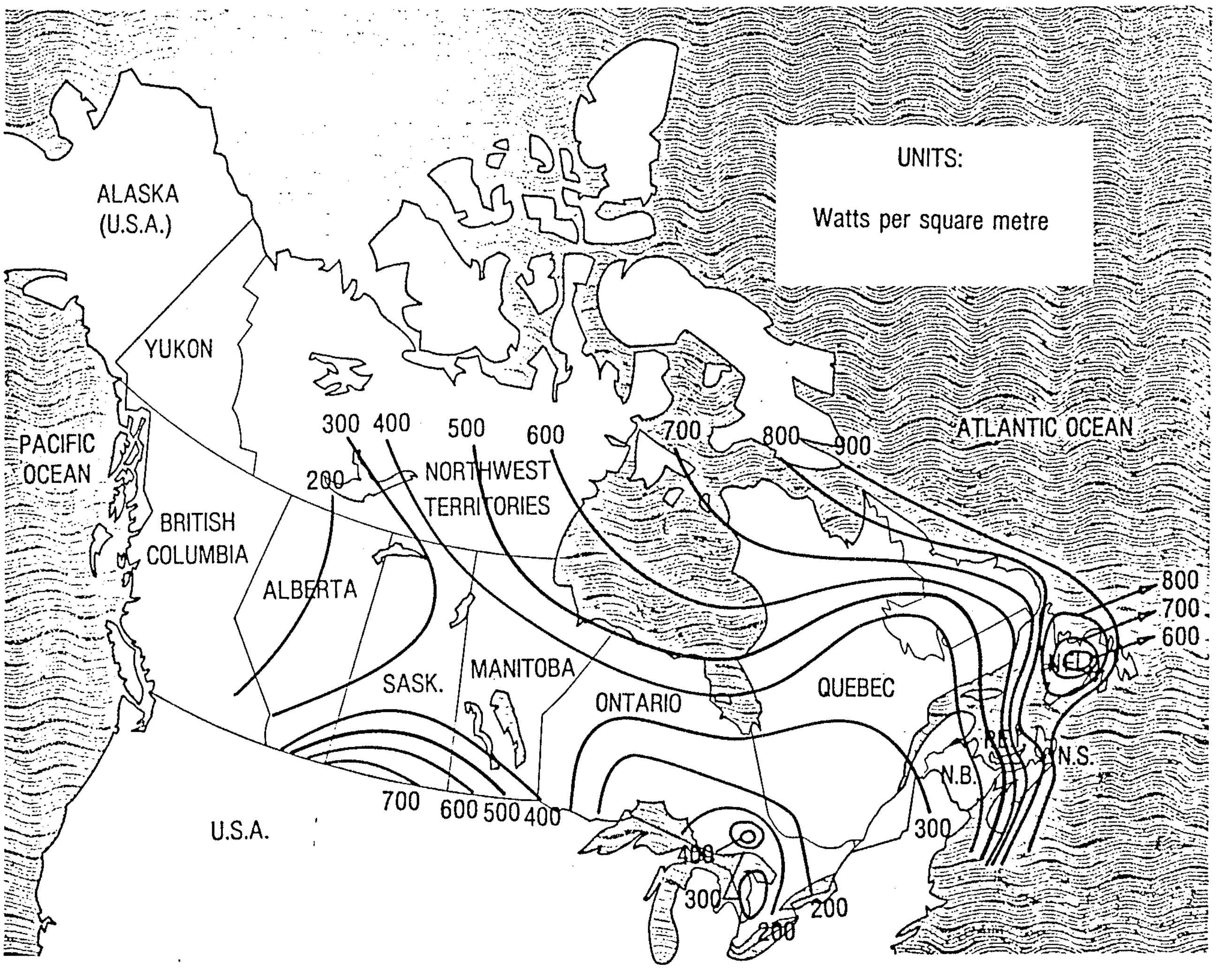
The use of the wind can be traced back to ancient times. The Egyptians and Chinese probably utilized some form of wind power possibly for grinding grain or similar uses. The earliest recorded use of windmills was in Persia several centuries before Christ. [35] Similar types are still being used in the remote areas of Iran today. It is surmised that the Crusaders, on their return from the Holy wars, brought back the idea to Europe. Wind power was extensively used by the Dutch up until the advent of steam power. At its height in the late nineteenth century up to 24,000 windmills were being used for a variety of purposes (the familiar four bladed wind generator). [36]

The development and expansion of hydro-generating stations and a national power grid in the 1950's spelled the death of the industry. It wasn't until the oil crises of the 70's and forecasted future shortages of oil that the development and commercialization began again in earnest.

Principles

Generally wind blows in all parts of the world but at varying speeds, direction and consistency. Overcoming these anomolies are the major problems in developing the technology. The accompanying map, Figure 13, shows the distribution of wind energy in Canada. The windiest parts of Canada are located in remote areas where energy use and demand is low but where the cost of energy is very high. These

Figure 13: Annual average wind energy density in Canada at 50 m altitude.



Source: Chappell, 1980, p. 2A:20.

areas are also far from electric power grids and natural gas availability, the two main sources of energy in Canada today. Wind power can then be a valuable energy source.

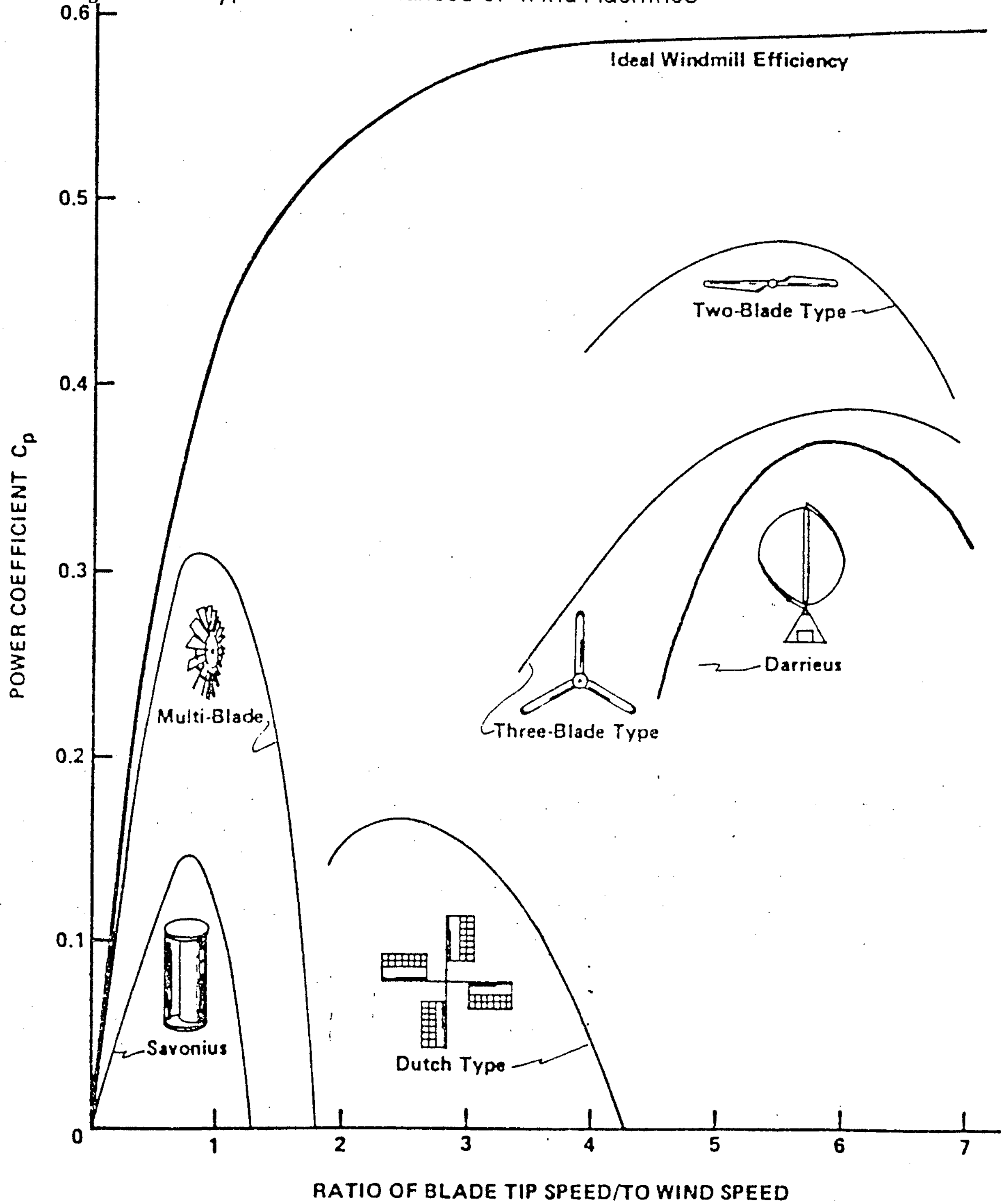
Aerodynamic fundamantals of lift and drag determine the utilization of energy from a moving column of wind. Simpler machines, like the Savonius rotor as shown in Figure 14, operate solely on drag forces. They can operate at low speeds however their efficiencies are limited. More efficient wind machines, like the two and three bladed turbines, use both the forces of lift and drag just like the wings of an airplane i.e. perform like an airfoil.

Wind power, and therefore energy, responds to the cube law - energy is proportional to the density of the air and the cube of the wind speed. The doubling of wind speed results in an eight-fold increase in power. [37] This is of great use. The faster the wind blows the more power is generated. However there is a problem: the speed fluctuates from minute to minute, the direction somewhat less. Due to the cube law the power then varies dramatically. A prospective site must be continuously monitored for at least a year to establish its potential for generating energy. A wind speed, averaging 12 mph (19 kmph), is required to make wind work well.

Systems

Research and development into wind energy conversion systems (WECS) has basically been involved with two basic designs - propeller

Figure 14: Typical Performances of Wind Machines



Source: Applied Aerodynamics of Wind Power Machines, Robert E. Wilson, May 1974.

and Darrieus wind generators. Figure 14 shows the typical performances of each type of wind machine.

Canada has concentrated its research efforts developing the vertical axis wind turbine (VAWT) while the United States and others developed the horizontal axis wind turbine (HAWT) system. From the National Research Council's point of view, development of the VAWT system is advantageous for several reasons: (a) it is more efficient, extracting more power at a given wind speed than a HAWT ; (b) it has a simpler configuration and operates at a higher speed than other wind turbines, which makes them well suited to electrical generation; (c) they are omnidirectional, that is they can operate in all wind directions; and, (d) the machinery that operates the turbine is located at ground level simplifying repair and maintenance procedures. [38] Its biggest drawback is the fact that it is not self-starting; it requires a power source other than the wind to start it in motion. A Savonius wind turbine has been added to the Darrieus turbine to start it up.

Darrieus windgenerators, in sizes ranging from 4 kW to 50 kW have been developed and are being used in various areas of Canada. Two 230 kW units have been installed in the Magdalen Islands in the Gulf of St. Lawrence and are being operated by Hydro Quebec and N.R.C. Smaller units are also being tested at the Atlantic Wind Testing site in Tignish, Prince Edward Island. Analysis has shown that, where diesel generators are used in remote areas, windgenerators are economically viable.

The next step in this development is the design and construction of windgenerators that can produce up to 4 MW of electricity (enough for 600-700 homes). "Project Eole" is a joint Hydro Quebec/Federal Government project that will construct a 4 MW wind turbine in the spring of 1986. The turbine will be a 200 ton 110 metre high Darrieus rotor held up by six guy cables supported anti-vibration masts installed at a cost of $35.2 million. [39] It will be located at Cap Chat in the Gaspe region of Quebec.

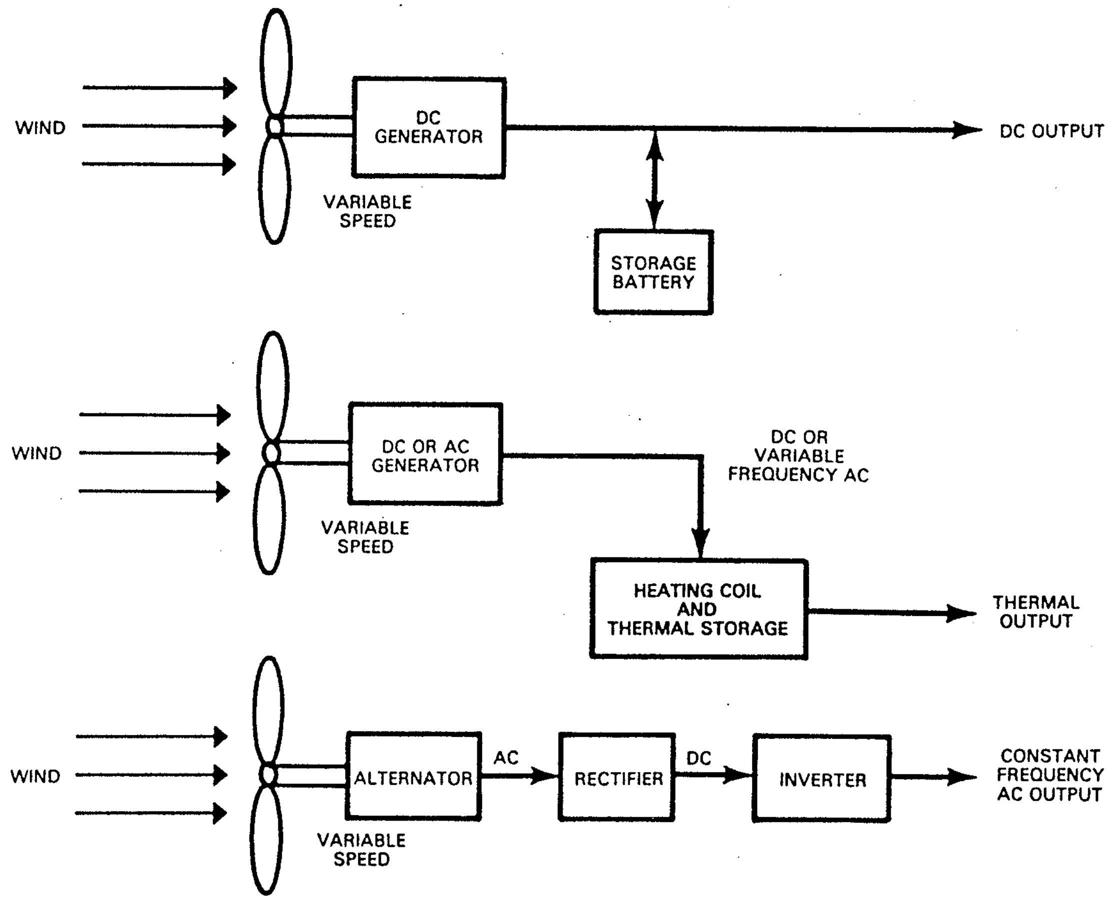
The United States and most other countries have developed windgenerators based on the horizontal axis, two and three bladed propeller concept. Development is quite well advanced today. The average power rating is 97 kW and increasing every month. At the end of 1985 there were 13,189 wind turbines installed in the U. S. with a generating capacity of 1,098 MW. Two and three bladed wind turbine units up to 750 kW are readily available on the market. [40]

The basic problem then, is to capture and turn the wind's kinetic energy of motion into a useful medium, such as electrical energy. At each step in the conversion process energy is lost. No system is 100% efficient (limited to the theoretical maximum - Betz efficiency of 59.3%) typically a VAWT system is on the order of 35% efficient and HAWT's 45%. [41] The main components of WECS are: a wind turbine, either VAWT or HAWT; an electrical generator (driven by the turbine); and, a storage medium, usually batteries, or elevated water storage tanks. However generators produce direct (DC) current whereas electric utilities provide alternating (AC) current. Alternators can be used to overcome this difficulty but they are not as efficient as DC generators, nor can the energy be conveniently stored and it requires a constant 60 cycles necessitating costly gearing mechanisms. Invertors can be used: they change DC power to AC; but, the total overall efficiency is reduced thus increasing the cost of the system. Figure 15 shows several methods of converting wind energy to electricity.

The upper limit on useful energy from wind power is a function of land area as well as wind regimes. Canada's large surface area and regionally excellent wind power regimes (often producing five more times wind energy per square meter than direct solar) combine to make wind energy a potentially vast new energy source.

Conclusion

A number of characteristics make wind energy an attractive energy source. It is a free inexhaustible source available everywhere. A windmill delivers high-grade mechanical power which can efficiently be converted into electricity so even small windmills (5-10 kW for example) can feed directly into an electrical power grid. Wind power allows small increments on a smaller scale than is the



Source: Frank R. Eldridge, ed., *Wind Workshop 2,* Proceedings of the Second Workshop on Wind Energy Conversion Systems, The Mitre Corporation, Washington, D.C., 9-11 June 1975, NSF-RA-N-75-050, MTR-6970.

Figure 15: Methods to Convert Wind Energy to Electricicty

case with most conventional generating units. This is considered advantageous where capital is scarce and/or energy demand grows more slowly.

In environmental terms, the harnessing of wind energy is in tune with the philosophy of maintaining the ecological equilibrium in that it draws upon a renewable energy source without upsetting the earth's ecosystems - unlike the case of fossil fuels, or even nuclear power plants. In economic terms wind energy is approaching cost-effectiveness in remote areas. In fact Ontario Hydro believes that wind is now competitive with diesel generated electricity.

GEOTHERMAL ENERGY

Introduction

Geothermal energy, in its broadest sense, refers to the heat produced deep within the earth's crust. Geothermal resources are available worldwide under most land masses but only where it is concentrated into restricted volumes, like iron ore deposits or tar sands, does it have economic potential. Its most evident and common occurrences are active volcanoes and geysers, the most notable being Krakatoa, St Helens and "Old Faithful". Hot springs, found in most areas of the world are another visible natural occurrence of geothermal energy.

The central core of the earth is composed of molten rock, primarily nickel and iron ore. The next layer is composed of semi-molten rock called the mantle. The layer nearest the surface, which is also the coolest, is called the crust. Normally it is fairly thin, when compared to the other two, some 20 to 50 kilometres thick. Heat is transfered from the high temperature surface, the earth's inner core, to the low temperature surface, the earth's surface. Averaged over the planet this geothermal heat gradient is approximately 25'C to 30'C per kilometre. [42]

In theory then, the aim is to find the hottest source that is closest to the surface. There are three types of energy sources that are available; hot water and/or steam, hot igneous systems, and molten rock (magma). These energy sources can all be tapped to provide useful energy in a number of ways however only two methods of are interest: producing geothermal electricity; and, using lower grade heat for space heating. [43]

History

The Soviet Union has a long history in developing geothermal energy resources. They began in 1947 to experiment with extracting energy from their geothermal sources. By 1975 they had 28 geothermal fields supplying almost 440 MW of non-electric energy for space heating, greenhouse operation and various industrial uses. [44]

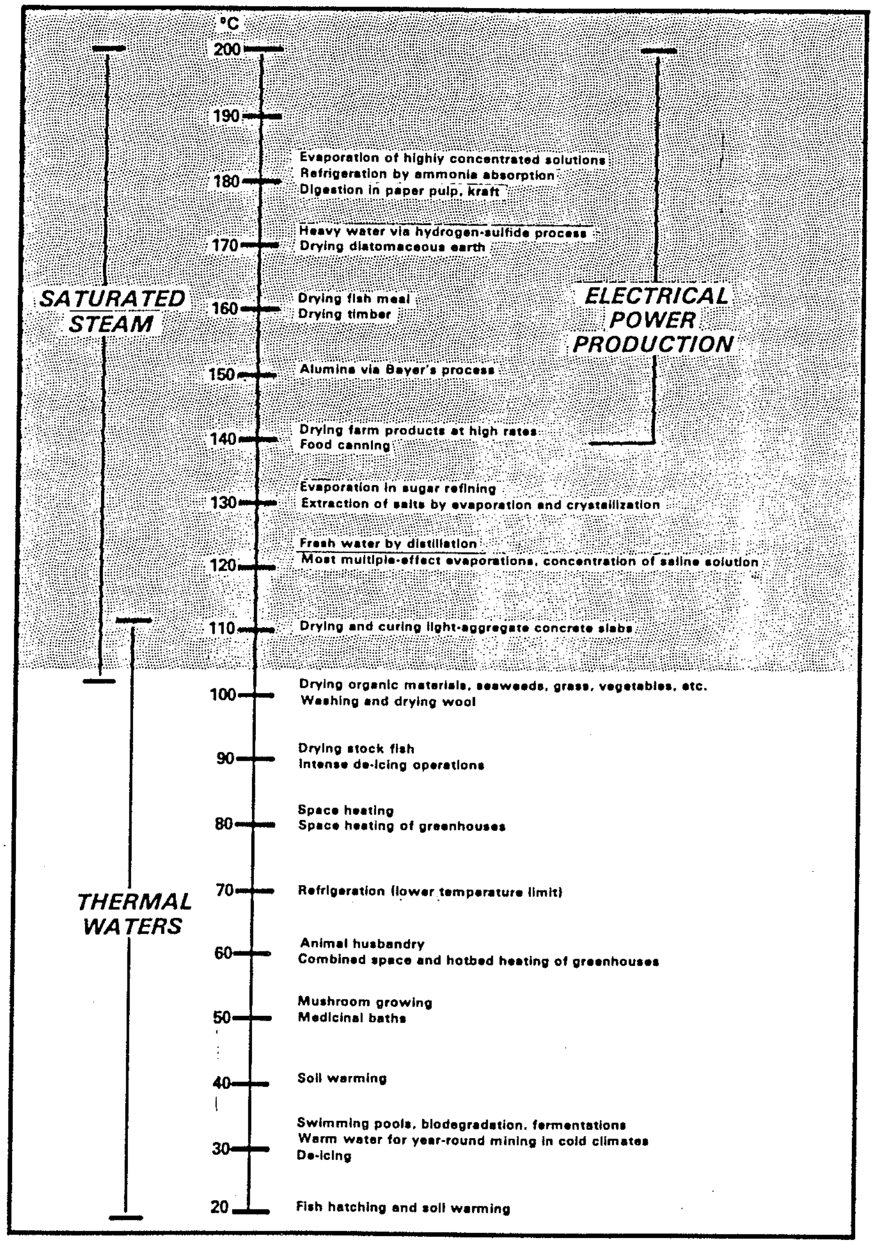
Other countries such as Italy, Iceland, Japan and New Zealand have been developing their resources for many years. [45] The first electric power generator in the world using geothermal energy was from a vapour dominated system that operated in 1904 in Larderello, Italy. Most of these countries use geothermal energy primarily for space heating and to a lesser extent for agriculture. The United States is expanding its main field in the Geysers area 90 miles north of San Francisco and developing several other sites mainly in the southern states. The Geyser field has been operating for twenty years and provides San Francisco with close to one half its electrical power. In general world geothermal energy production has expanded slowly over the last two decades.

Canada, on the other hand, is a relative newcomer to the field. Research has been going on for some ten years but it has been strictly limited to locating promising areas for development. The Earth Physics Branch of the Department of Energy, Mines and Resources is the government agency responsible for coordinating geothermal research.

Principles

Geothermal resources can generally be categorized under three headings - hydrothermal deposits; hot igneous systems; and conduction-dominated systems. [46] The geology of the earth at varying locations around the world is responsible for different types of geothermal resources being available. Figure 16 details the range of

Figure 16: Typical geothermal fuild temperatures for representative direct-use applications.

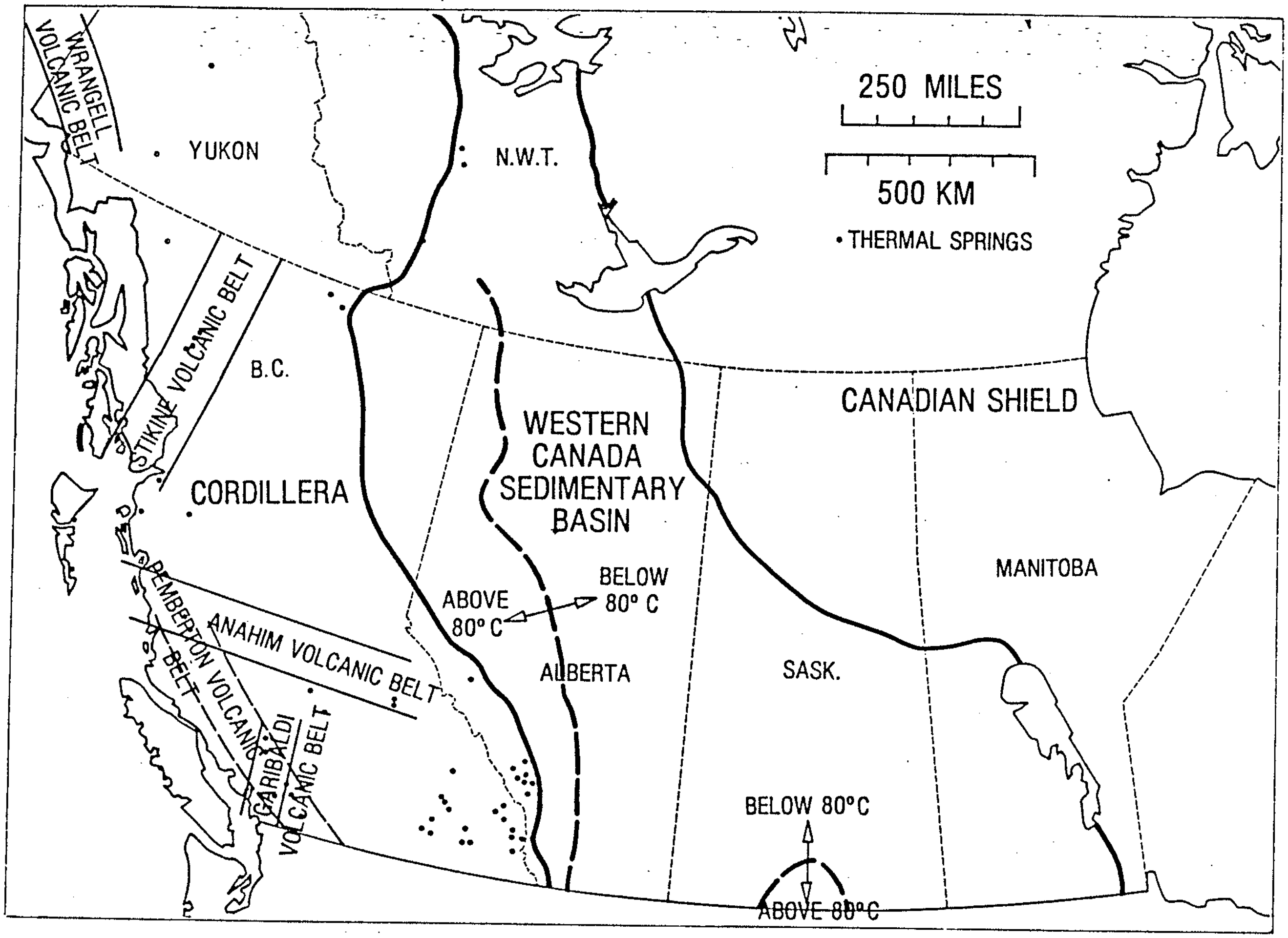


Source: Handbook of Geothermal Energy, Edwards, L.M., 1982, pg 96.

geothermal temperatures available and a representative sample of direct-use examples.

The general geology and tectonic activity [47] of an area determines its potential to produce geothermal energy of one form or another. One type of tectonically active region that shows consistently high heat flow values lies along the border of tectonic plates. Fracture systems in the crust may allow the heat generated by the interaction of these plates to be transported to or near the earth's surface. The geothermal areas of the world are concentrated along the margins of the major plates. Figure 17 shows the geothermal potential of the Prairies and B.C. Geologically the Prairies lie on the Western Precambrian platform and B.C. lies on the Western Cordillera and the Laramide Foldbelt. [48]

There are three areas in Canada that show potential for geothermal resources - Atlantic Canada, the Prairie Provinces and the interior of British Columbia. The geology of Atlantic Canada indicates that geothermal activity is quiet. However, two areas-the Fredricton basin and the Stellarton area of Nova Scotia show promise for low-temperature energy. [49] The central platform area (sedimentatry basin) of the Prairies and the western cordillera in the interior of BC show promising signs of low-temperature energy, suitable for space heating. [50] Figure 17 illustrates that Gypsumville lies in an area which exhibits geothermal potential.



Source: After Souther, 1975, p. 263; and Jessop, 1976, p. 5.

Figure 17: Geothermal potential in Western Canada.

Hydrothermal Deposits

Hydrothermal deposits consist of high temperature water (liquid dominated) and/or steam (vapour dominated) contained in reservoirs (aquifers) rocks. [51] Figure 18 offers a simplified schematic drawing of hydrothermal reservoirs. Gravity and convection carry the hot water and/or steam through faults and fractures in the rock to a point near the earth's surface. As in oil exploration drilling a hydro-thermal well then brings the stored heat in the water and steam to the surface where it can be transformed into energy. This energy can be used for heating if it is hot water or for electricity if steam (steam can also be used for heating).

This steam is usually saturated and superheated, often to temperatures nearing 250'C with some traces of carbon dioxide and hydrogen sulfide. The steam can be fed directly to turbines for the production of electricity. The Geysers' project in California is the largest and best known plant using steam. [52]

Hot Igneous Systems

Hot igneous systems comprise two sources of energy--magma and hot, dry rock deposits. Magma is in reality molten rock, many miles below the earth's surface, commonly called lava when it reaches the surface.

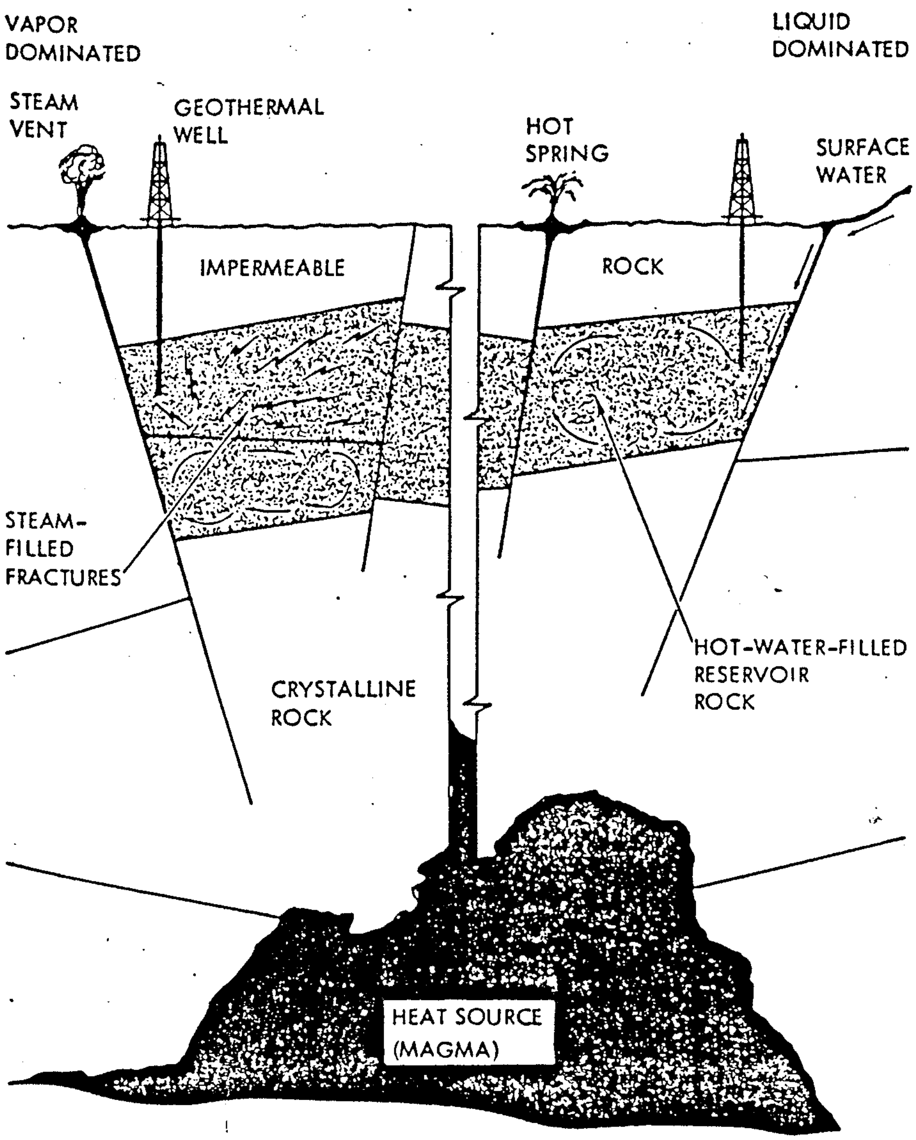


Figure 18: Generalized (simplified) schematic diagram of a hydrothermal reservoir. (After Leibowitz, 1978; courtesy of Energy Sources.)

Hot dry rock deposits are located above the magma, some 6000 to 15,000 metres below the earth's surface. They are impermeable, usually composed of granite in North America, and transfer heat by means of conduction to the next layer of the earth's crust. Extraction of the heat energy is still in the experimental stage but two methods have been identified.[53] The first involves using explosives, even nuclear, to blow a cavern deep in the rock and with the circulation of water to the surface extracting the energy. The other method, which has the same result, is hydrofracturing i.e. creating fissures in the rock, injecting water into the fissures and extracting the heated water through another drill hole. British Columbia has the potential to exploit its hot dry rock deposit but its development will have to wait until the technology has been proven and the energy can be economically extracted.

Conduction Dominated Systems

This system is comparable to hydrothermal systems except that energy transfer is achieved by conduction rather than convection. Two sources are available, sedimentary reservoirs and geopressured deposits. Sedimentary reservoirs contain water usually at a temperature of 100°C and located some 5-10 km deep.[54] This water is usually static or slowly moving. The USSR and Hungary have utilized these reservoirs for space heating and for agriculture.[55]

Geopressured reservoirs occur in sedimentary basins found in Tertiary age geosynclines.[56] These basins have been formed and compacted over a short period of time, geologically speaking. In addition to the hydrodynamic and thermal energies of the hot water there is natural gas associated with these basins increasing their potential viability. Geopressured reservoirs show promise but research has not progressed to a point where extraction is economical.

Energy Production Systems

(a) Vapour-dominated systems

The Geysers is the best known and largest geothermal generating plant in the world. Dry steam is the working fluid and is fed directly into turbine generators where electricity is produced. This geothermal area, 90 miles north of San Francisco, covers approxiamtely 160,000 acres and generating capacity approaches 1,000 MWe. About 900,00 kg of steam per hour are needed for every 110 MWe generated, an amount supplied by 14 wells at 180'C and 7 kg/cm^3 with a net thermal efficiency of 14 to 16 per cent.[57] This is one of the few fields in the world that operate on dry, hot steam.

(b) Liquid-Dominated Systems

Energy production is more complex with this type of system due to differing liquid temperatures, pressures and salinity. Modes for generating energy include steam turbines, binary cycle, hybrid cycle and total flow concept. Generally the temperature and degree of salinity dictate the generating mode and end-use energy (be it space heating, process heating or electricity).

Liquid dominated systems use two primary methods for extracting energy - flash steam systems and secondary fluid (binary) systems. A third method - total flow systems - has not been seriously developed. The percentage of salinity has an impact on all three systems. The higher the amount of dissolved solids the more problems there are with erosion, corrosion and scaling.

Conclusion

Manitoba is in the prairie central platform area where hot water (hydrothermal-liquid dominated system) at less than 80'C is probably available. Sufficient data has not been collected to confirm the exact nature of the geothermal deposits in the Gypsumville area or to determine the economic viability of the energy recovery system. However there are systems in use today that could be utilized to recover heat energy from any deposits that might be found in the future.

BIOMASS ENERGY

Biomass energy can simply be described as chemical energy which is stored in plant tissues, animals and animal products converted from solar radiation via photosynthesis. The resultant release of this energy can produce, in the broadest sense, heat and/or electricity. Figure 19 illustrates the main features of biomass technology. Specifically Smil has defined biomass as: [58]

> "it refers to any plant mass harvestable for conversion to fuel, as well as to animal wastes convertible to solid or gaseous fuels. As these wastes are overwhelmingly nothing but undigested residues of plants, the umbrella term *phytomass* would perhaps be preferable, with *biomass* reserved for both of the living masses making up the biosphere, the mass of autotrophs (phytomass) and the mass of heterotrophs (zoomass, including humanity, for which the separate term of *anthropomass* might be used to set man apart for adherents of the Judeo-Christian tradition)."

For our purposes, however biomass will be more simply defined as:

> "all plant and animal material that can be converted into energy."

Biomass resources used in these processes include crop, forestry, municipal and livestock wastes, and products grown especially to fuel these processes such as wood, algae and kelp from energy plantations.

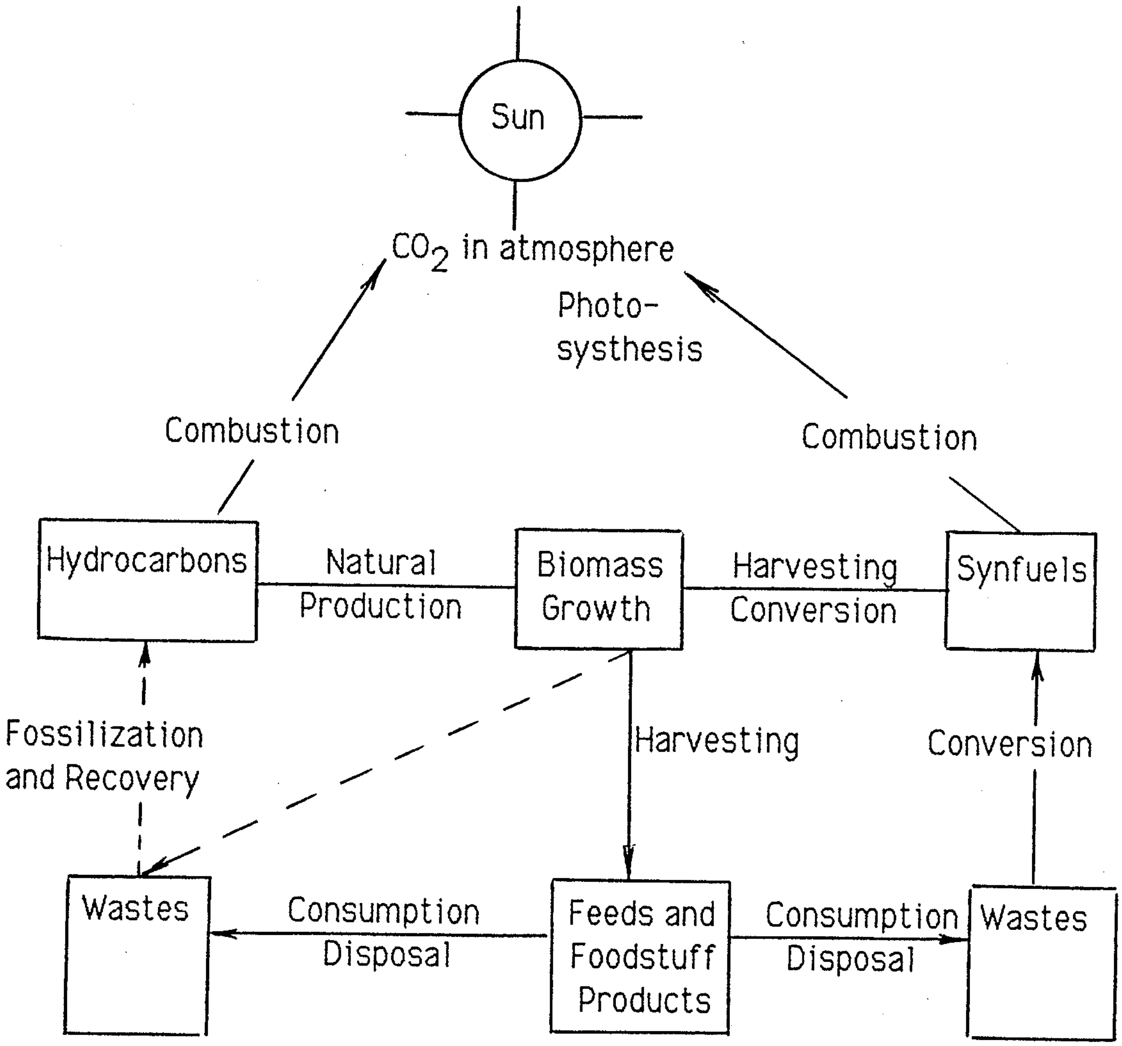


Figure 19 Main features of biomass energy technology

Source: After Klass, Energy and Synthetic Fuels, p. 713.

History

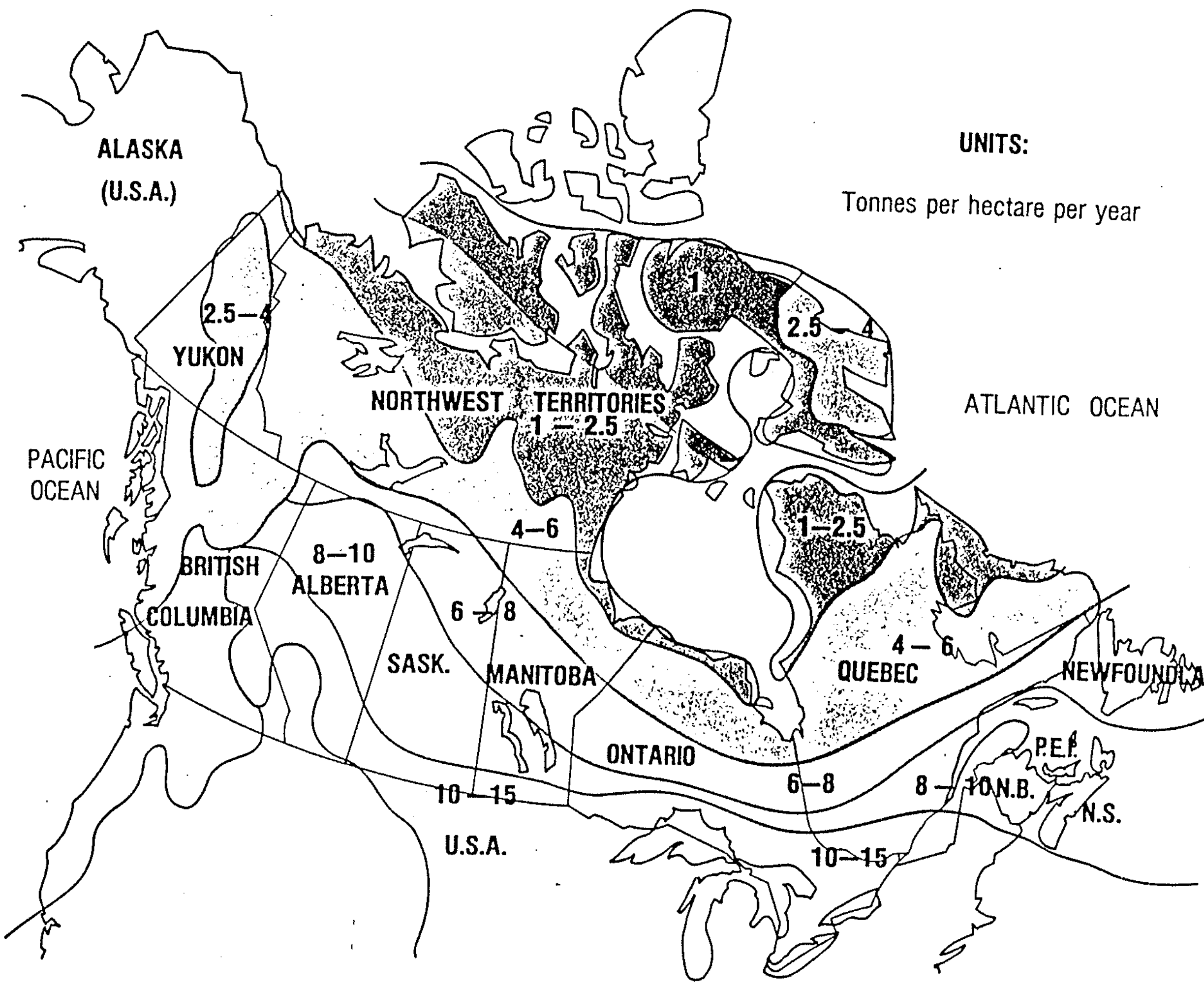
Direct combustion is the most obvious and simplest method to derive energy from biomass. Wood and animal manure have been used from time immemorial to produce heat for mankind. However, their use declined rapidly with the coming of the fossil fuel age early in the 20th century. Subsequently interest in biomass, to provide heat and moreso electricity has increased due to the energy crisis and the resultant government programs to reduce dependency on fossil fuels.

Canada is in a very fortunate position with respect to wood as an alternate fuel source. Wood, that has been advanced as being ideal for heating-such as poplar and birch, is not used by the pulp and paper and lumber industries. Therefore, the two uses would be mutually exclusive with enough wood to go around if properly controlled and managed. It has been estimated that there is enough wood available to heat all the homes in Canada. Figure 20 details the biomass productivity zones in Canada. Gypsumville is located in the zone that has the second highest productivity rate.

Principles

Biomass resources available for energy conversion run the gamut from algae to municipal solid waste to short-rotation forestry (as per Figure 19). Three general categories can be identified: (1) residues including both forest and agricultural; (2) energy crops

Figure 20: Biomass productivity zones in Canada



Source: Love and Overend, 1978, p. 8.

including trees, agricultural products; and, (3) wastes including sewage, solids and industrial.

Forest residues include those residues left over from various forestry operations that harvest commercial timber including loggingresidues such as chips, bark and sawdust, trees removed in thinning (intermediate cuttings), understory removal and dead trees. The quality of the energy produced (joule content) varies depending upon the species of the residue, the wood:bark percentage and the moisture content. Obviously the drier the residue the more efficient is the combustion. Also included in the equation for cost effectiveness is the distance the residue has to be transported. For many operations the ideal condition is to burn the residues on site. Gasification is probably the best process for converting this biomass into energy.

Agricultural residues can be classified into primary and secondary raw material biomass for conversion into energy. Primary residues include those portions of the crop that are left in the field after harvesting (wheat and rice straws, sugarcane bagasse and corn stalks). Secondary residues include those by-products left at the elevators. Again distance is important and an added complication is that some residues must be left on the fields to aid in fighting soil erosion and ingesting of nutrients into the soil.

Energy crops are those crops grown specifically for energy production including short-rotation forestry, agricultural crops and aquatic plants on energy farms. Trees are the most obvious source of biomass energy production. The concept in short-rotation tree farms is to optimize the biomass output taking into account the cost of the operation. Quick growing trees are planted in high density and harvested at regular intervals typically 4-5 years allowing the trees to regrow from the stump (coppicing) and single stem harvesting with intervals 12-20 years.[59] The intention is to choose those trees that grow quickly but are not required by the forestry industry. In addition prime agricultural land should not be used for tree plantations i.e. not replacing food crops with tree farms. Tree species that have been proposed include cottonwoods, sycamore, red alder and hybrid poplars. Direct combustion or gasification would be used to produce energy products.

Agricultural crops that have been suggested for energy plantations include sweet sorghum, corn, sugarcane and sugar beets. Research has not progressed to a point where crops can be considered viable at this time. Fermentation, with ethanol as the by-product, is the process that would be associated with crops.

Aquatic biomass includes those aquatic plants that can be found in fresh water such as water hyacinth and duckweed and in salt water such as seaweeds, microalgae and kelp. These have not been investigated thoroughly enough to be of any use, especially in western Canada. Anaerobic digestion would be the preferred technology to convert this biomass to energy in the form of biogas.

Wastes is a general term encompassing many biomass resources including manure from animals, generally cattle, swine, sheep and poultry, to sewage. Animal manure produces two useful products: a residue that can be used for fertilizer; and, a medium joule value gas. In the United States cattle and poultry are the main sources for manure. Several plants in the United States are being constructed to produce methane and fertilizer from cattle manure from major feedlots and stockyards. A by-product from this process is fertilizer. Anaerobic digestion is the process used to convert manure to methane.

Industrial wastes includes by-products from food processing plants and some chemical industries. Food processing plants include canneries (both vegetable and fruit) freezing plants, slaughterhouses, sugar mills, breweries, distilleries, and bakeries. [60] Organic plants and coal carbonization are examples of chemical industries. Anaerobic digestion and fermentation are the processes involved in this application.

Solid wastes are produced by every household and factory in the world today. A city the size of New York and Toronto produce garbage at an alarming rate and it is increasing every year. One suitable use of this biomass is for energy production. The composition, quantity and type of municipal solid wastes (MSW) varies greatly day to day and region to region. The economics of resource recovery depend upon the efficiency of the operation, the quantity of the energy produced and the value of the materials recovered.

MSW contains combustible material, moisture and ash; the latter ingredients, once removed, provide twice the heating value as that of as - received MSW. In addition non-combustible components such as glass, iron and steel, aluminum and non-ferrous substances must be removed prior to burning and can be disposed of by selling as scrap. There are many systems, both European and American, that are available to provide energy through waste destruction (typical efficiencies range from 37 to 70 percent). The three most common European systems are the reciprocating grate, roller (drum) grate and reverse reciprocating grate systems. The first American system was the travelling grate but this has generally been superseded by the suspension fired system. Most systems are built with water-wall construction. Pyrolysis and starved air systems, a combination of pyrolysis and incineration, are other methods of resource recovery. Incineration is, by and large, the most popular system.

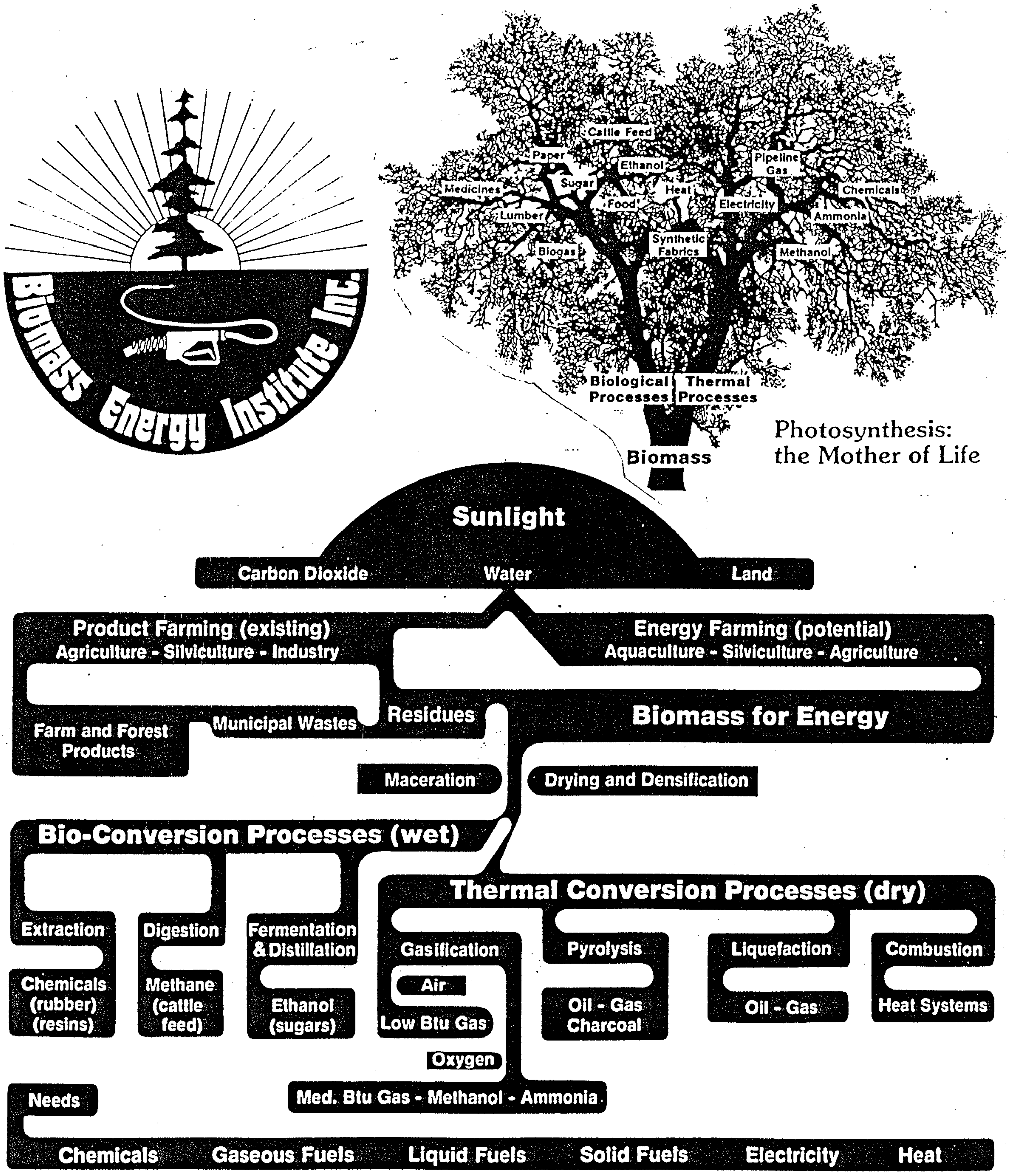
Landfill sites are another source of energy, primarily methane gas including varying amounts of nitrogen, carbon dioxide and hydrogen sulfide. This gas is produced within the landfill itself by anaerobic decomposition of organic waste material. It can be burned directly or scrubbed to remove the unwanted components thus increasing its joule value by as much as 300%. A number of factors affect the amount of gas produced including air infiltration, site construction and the gas recovery system. The system for collecting, removing and purifying the gas is a well-proven and economically feasible process.

Human wastes is another source of energy. Nearly every town and city in North America has a sewage disposal plant that can be used as the source of energy. Anaerobic digestion is once again the main process for producing energy in the form of methane gas and fertilizer. Codisposal systems, utilizing solid waste and wastewater treatment sludge as the fuel, is also widely practised in the United States.

Energy Conversion Systems

Conversion technologies have generally been classified by two different means: firstly by the method of breaking down the biomass into useable components i.e. biological or thermochemical reactions;[61] and secondly, by the type of process used i.e. wet or dry conversion. Both methods incompass the presently known bio-thermal reaction processes. Figure 21 illustrates the current methods of energy conversion and the direct-use applications of the products.

Figure 21



Biomass Energy Paths

Biological Conversion

Biological conversion entails energy-yielding enzymatic breakdown of biomass by micro-organisms under anaerobic conditions. The main systems are (1) biomethanation (anaerobic digestion) which produces methane and carbon dioxide, a fuel gas; (2) ethanol fermentation, which produces a liquid fuel; and (3) other anaerobic microbiological processes using acetone-butanol, acetic acid, and other fatty acids.

Anaerobic digestion (biomethanation) [62] is a well known process that is used in the treatment of sewage world wide. It involves the decomposition of organic materials such as industrial wastes, animal manure, municipal solid residues and sewage, in the absence of air, to produce methane and carbon dioxide. The methane that is produced is commonly called biogas.

This is a two-step process, primarily carried out in a digester. The first step involves the breakdown of the wastes by several types of bacteria - hydrolytic, acetogenic and homoacetogenic - into organic acids; and, the second step transforms these acids (using methanogenic bacteria) into methane and carbon dioxide. The gas produced can be burned directly or "scrubbed" to remove the carbon dioxide thereby producing a higher joule value gas.

Fermentation [63] is a well known process that has been used for many centuries to produce alcohols, mainly ethanol. Many raw materials have been used over the years including sugars (sugar cane, sugar beets, sweet sorghum and molasses) starches (potatoes and cereal crops) and lignocellulosic (wood, agricultural and forest residues) materials. Processes using other than sugars as raw materials have an additional step - using hydrolysis to reduce the raw materials to sugars.

Thermochemical Conversion

Thermochemical conversion involves the use of high temperatures to convert biomass into useful energy by-products. The processes include (1) direct combustion to produce heat; (2) pyrolysis to produce biogas, pyrolytic liquids, chemicals, and charcoal; (3) gasification to produce low or intermediate joule value gas; and (4) liquefaction to produce heavy fuel oil or, with upgrading, lighter boiling liquid products used as distillates, light fuel oil, or gasoline.

Direct combustion in its simplest form has been used as a form of producing energy for many centuries. Basically it was used to provide heat and for cooking using fuelwood and charcoal. Systems used include open fires, wood stoves and furnaces, package boilers and fluid bed units. The heat produced is used for heating and for the production of steam for electricity. Biomass used includes forest residues from the pulp and paper industry, agricultural residues and pulp liquors.

Direct combustion transforms municipal solid wastes into energy through two means; (1) conventional incineration where the wastes are burned on travelling grates, and (2) fluidized-bed combustion where wastes (shredded and separated to provide a homogeneous fuel) are suspended in an air mixture and burned. An incinerator with a heat recovery system is one of the simplest forms of energy recovery that can be used for small communities (steam for heating and/or electricity).

Pyrolysis, the thermal decomposition of biomass materials in the absence or near absence of oxygen, is a means of producing fuel gas, liquids, and chars with the quantities of each determined by the pressure, temperature, residence time, catalysts, and reactor charge mixture.[64] This is a thermochemical process requiring heat to produce energy. One example is the destructive distillation of wood and other agricultural products, and municipal solid wastes to produce methanol, charcoal and low joule value gas. The resultant fuels can be used for space heating and the generation of electricity. This process is a multi-stage one involving high temperatures that make pyrolysis feasible in large scale operations.

Gasification is defined as the reaction of carbonaceous materials with an auxiliary gas such as air, oxygen or hydrogen to produce a mixture of carbon monoxide, hydrogen, carbon dioxide, methane, some tar, and char.[65] Steam can be used but it has a disadvantage in that it must be carried out at high pressures, typically above 7 bars. Oxygen or hydrogen while reducing the nitrogen content of the gas, must first be separated from air thereby increasing the cost and energy consumption. Gasification is different from pyrolysis in that no additional heat is required and the composition of fuel gases is different.

Present research centers on the production of medium joule value gas, high joule value gas or substitute natural gas. Woody biomass is to be the preferred fuel due to its relative abundant supply. Steam and/or oxygen rather than air will be used. In this process the unnecessary by-products such as carbon dioxide, hydrogen sulfide and water vapour are removed and methanol is produced.

Liquefaction [66] is defined as a thermochemical process which at high temperatures and pressures and in the presence of catalysts yields liquids. This process uses a portion of the product oil to prepare a slurry of biomass. The slurry plus catalyst is pumped into a reactor at a temperature of approximately 400°C and pressure of 30-40 atmospheres. Liquefaction does produce a clean fuel similar to heating oil, but the necessity of high pressures increases the energy and capital costs to a prohibitive level.

Conclusion

The types and varieties of biomass that are available on a world-wide basis for conversion into energy are numerous. However once a specific site has been chosen the types of biomass are greatly reduced due to location, climate and availability. Direct combustion of wood is still considered the best method for producing energy in the form of steam for space heating and for electricity. The second choice would be the utilization of municipal solid waste, also for electricity and space heating, and the third would be the transformation of sewage into energy in the form of biogas.

Quantification of energy available for the biomass sources can be broadly stated. Figure 20 illustrates that Gypsumville is in the medium productivity zone having approximately 8 to 10 tonnes per hectare per year harvestable biomass. Looking at combustion of wood for example, this amount would provide six cords of wood equivalent to 150 x 10^6 Btu's or close to 1000 gallons of oil.

NUCLEAR ENERGY

Introduction

Nuclear energy is released by two processes - fission and fusion. Fission involves the splitting of a heavy atom, usually uranium, into two or more fragments releasing significant amounts of energy. [67] This is pure uncontrolled energy in its basic form, but this energy can be transformed to do useful work. Fusion power, in its most abundant form, is found in the stars i.e. a star can be considered to be one large nuclear reactor. Fusion involves the conversion of mass to energy ($E = mc^2$) by the joining or fusion of two light atoms, usually hydrogen or helium into a heavier one. Tremendous amounts of energy are released by this process.

The basic operation of a nuclear power plant is relatively simple in theory. The process of nuclear fission and fusion release energy which is usually used to boil water to produce steam which in turn drives a turbine connected to a generator that produces electricity.

Nuclear Fission Power

History

Fission was first discovered in February, 1939 but it was not until December 2, 1942 that the world's first self-sustaining nuclear fission chain reaction was successfully achieved at the University of Chicago in the United States. [68] At this time the prime reason for its development was to produce an atomic bomb. It wasn't until the end of the second world war that commercial reactors were built with the prime purpose of generating electricity.

The period 1945 to 1953 saw the development and construction of many experimental research reactors in the United States, USSR, Britain and France. The first commercial small reactor, a pressurized water reactor (PWR) was built for the U.S. Navy in 1955 that powered the submarine USS Nautilus. The design was so successful that it is still being used today. This development paved the way for the construction of the first nuclear power plant in the United States, at Shippingport PA. It attained its design power output of 60 MW electrical/230 MW thermal December 23, 1957.[69] From this starting point many countries began developing a nuclear power industry.

Principles

Each country developed its own design based either on previous technical knowledge and/or availability of materials. Many designs, involving different types of fuel, coolant and moderators have been developed, constructed and become operational. Several of the most popular designs are: (1) light water design, consisting of boiling water reactors (BWR) and pressurized water reactors (PWR); (2) high tempera- ture gas cooled reactors (HTGR); liquid metal fast breeder reactor (LMFBR); and, (4) heavy water moderated reactor, the CANDU.

Basically the coolant, whether it be gas, liquid metal or heavy water, transfers heat to water, creating steam that in turn drives turbines that generate electricity.

Canada has concentrated its efforts on the CANDU (Canadian Deuterium Uranium) design. The best known example of this type of reactor is the Pickering Nuclear Power Generating plant in Central Ontario. Originally operational in 1971 it has produced more electricity than any other nuclear plant in the world. Construction of other large plants followed, including Pickering B, Bruce and Gentilly. Nuclear power plants now produce approximately 10 % of the total electrical energy in Canada, with most plants, 13 CANDU's, concentrated in Ontario. Today there are 22 operating CANDU reactors with a total output of 12,250 MWs. [70] Figure 22 illustrates the CANDU reactor system.

This thesis is interested in small reactor designs providing 2 MW to 10 MW of power, whether in the form of heat or electricity. Canada is again one of the world leaders in small reactor designs, such as the SLOWPOKE, a promising breakthrough in small reactors.

Systems

The SLOWPOKE (Safe Low Power Critical Experiment) concept is being specifically designed by Atomic Energy of Canada Limited (AECL) for use in remote communities. The power range for this application

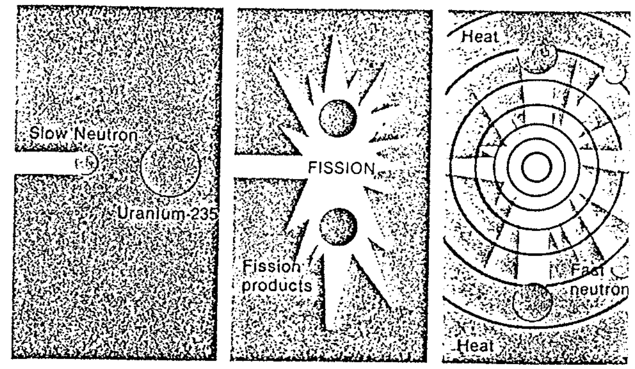
Figure 22

The CANDU System

Nuclear power reactors maintain the fissioning of uranium to produce heat. There are different reactor systems available but the one developed and used in Canada is called CANDU (CANada Deuterium Uranium). This name summarizes three of the reactor's distinguishing features: the system is Canadian; it uses heavy water (deuterium oxide) as moderator; and the fuel is natural uranium.

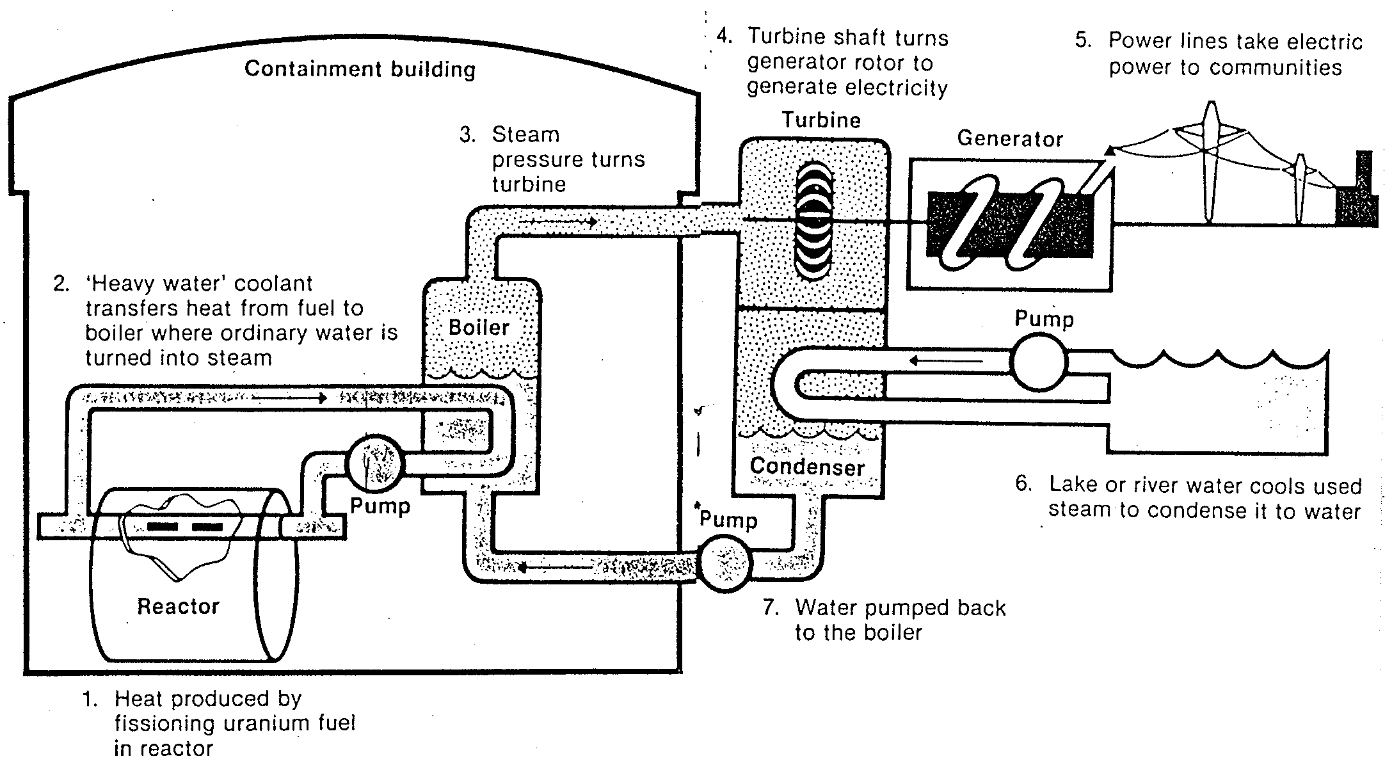
Fission reactions in the fuel produce heat and fission products or "wastes". The heat is removed by heavy water pumped over the fuel and is used to produce steam which turns the turbine generators to generate electricity. The fission products remain fixed in the fuel.

CANDU fuel bundles each weigh about 24 kilograms. Several thousand fuel bundles are contained in each reactor, held in horizontal pressure tubes through which the cooling water flows. Heavy water moderator, without which the reaction would not take place, surrounds the pressure tubes.



When a slow-moving neutron strikes the nucleus of a uranium-235 atom it splits it into fission products which fly apart creating heat. Neutrons given off at the same time are slowed down by the heavy water moderator and are able to split other uranium-235 atoms and thus maintain a chain reaction.

CANDU pressurized heavy water nuclear power process



Source: AECL Nuclear Power CANDU Reactor Safety, July 1980.

is in the order of 2 MW $_{(th)}$ to 20 MW $_{(th)}$.[71] AECL 's strategy has been to develop a simple, safe and economic reactor concept based on a proven design. Slowpoke is a low temperature pool-type reactor similar to those used for research at several Canadian universities. Its purpose will be to heat unpressurized water, which can in turn be used to heat buildings. In fact several could be hooked up in series for the production of electricity. This is done by passing the hot water from the reactor through heat exchangers where an organic liquid is vaporized to drive turbines. The reactor is designed to be self-contained and licensed to operate without an operator in the reactor room. It can be turned on with a switch (not necessarily located in the reactor building) and can reach full power in a matter of minutes. The reactor core would be designed to be replaced as a unit every two years.[72]

The major components of the Slowpoke reactor are detailed at Figure 23. As can be seen the reactor does not comprise a series of complicated components and great lengths of high pressure piping running in every direction. The reactor is not much more than the size of a double car garage filled with water and placed on its end enclosed by concrete and buried in the ground, preferrably bedrock. The fuel assembly, uranium (5 per cent enriched) oxide pellets encased in zirconium metal alloy tubes is about the size of a bread-box and is placed at the bottom of the pool.

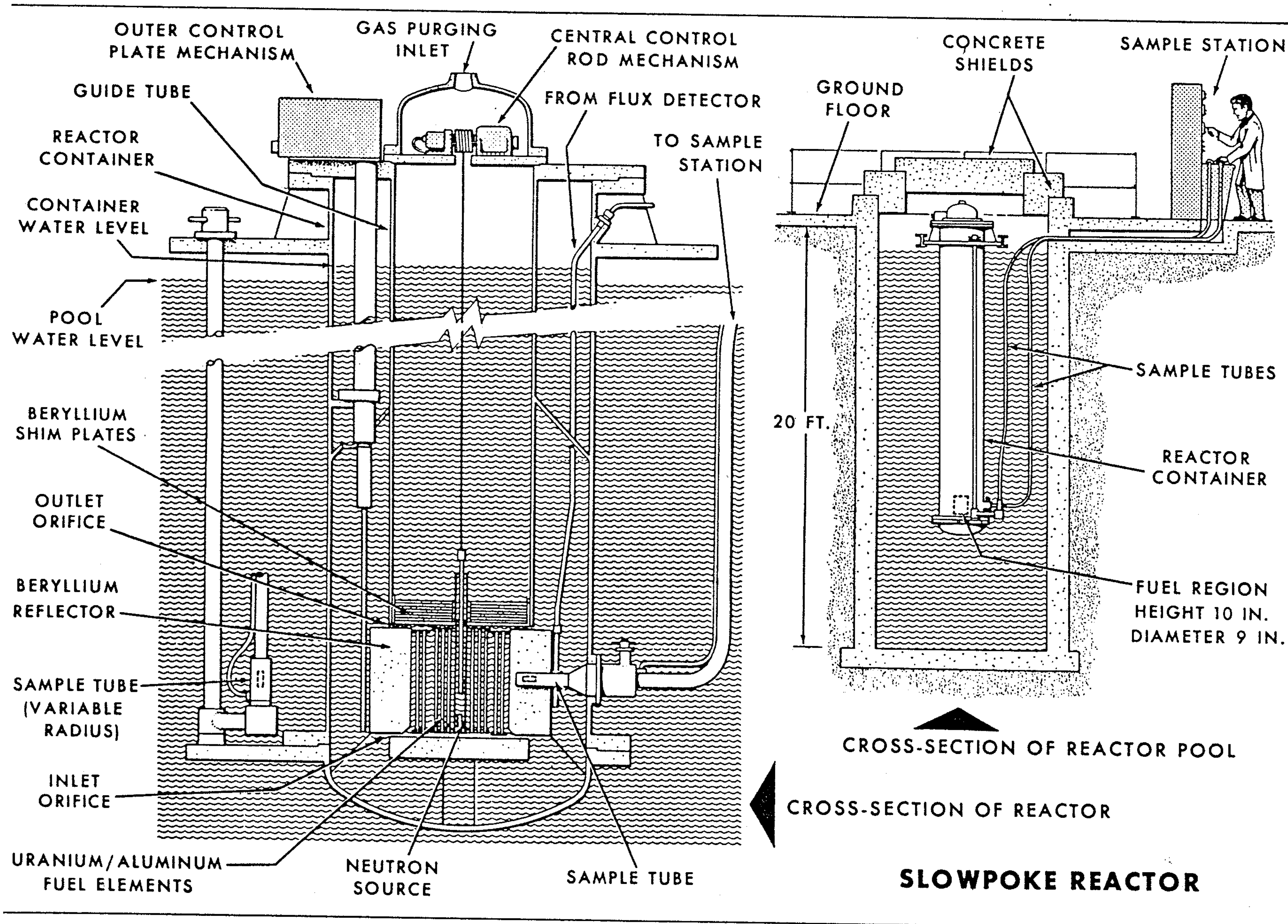


Figure 23

Source: AECL 7438, Small reactors for low temp heating, 1981, pg 2.

The novel features of the SLOWPOKE reactor concept are low critical mass, inherent safety and unattended operation. Low critical mass is achieved by surrounding a small U^{235} aluminum-water core with a beryllium reflector. This is important because of the low consumption of uranium, the reduced amounts of shielding, cooling water and fission products thereby reducing the overall cost. Reactor power is controlled by a motor-driven beryllium annulus surrounding the core, responding to a signal from a temperature sensor. The coolant temperature is usually maintained at 80'C. [73] Core cooling is by natural convection and the pool water is separated from the hot water delivered to the consumer by the heat exchangers.

A melt-down, the common fear for existing large reactors (typical examples are Three Mile Island and Chernobyl) cannot occur since the fission reactor does not produce enough heat to melt the zirconium tubes that hold the fuel pellets. The reaction is temperature controlled so that if the system fails the rate of fissioning declines and the reactor would eventually shut itself off.

If Slowpoke is to be a viable alternative it will have to exhibit several important factors -- low capital and operating costs and a short construction and licensing period. AECL economic analysis indicates that it compares favorably with electricity and imported oil, but not with natural gas (costs based on Southern Ontario). [74] As there is little natural gas and hydro power available at many remote northern locations, where most rely on diesel fuel, cost comparisons are very favorable.

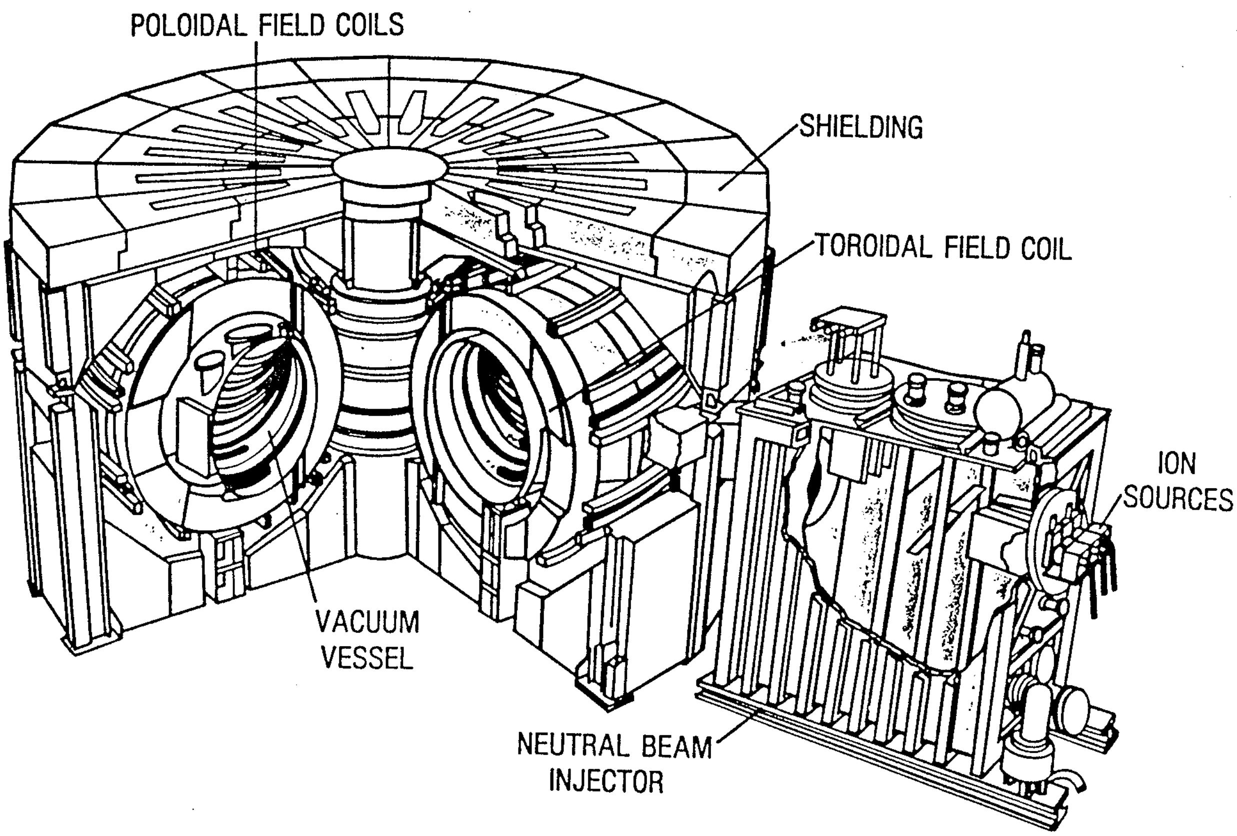
Nuclear Fusion Power

Nuclear fusion power is in its relative infancy. The physics of fusion reactions are well known but the technology is not well developed.[75] The process must be carried out at extremely high temperatures (100 million degrees Kelvin) and pressures (1000 times that of conventional solids).[76] Basically, the conditions found in the stars must be recreated in the labratory. The best known fusion reactor protype is the Tokamak Fusion Test Reactor, using magnetic confinement principles, that is being developed at the Plasma Physics Laboratory in Princeton, N.J. It is being developed because of its simplicity, theoretically speaking, as it has the lowest required ignition temperatures.[77] Figure 23 illustrates a generalized represenstation of the Tokamak prototype reactor.

Fusion power has been developed and supported because of its tremendous energy potential and the fact that one of its main fuel components deuterium, found in ordinary water, is readily available. The heat generated by a fusion reactor can be used in several ways: for district heating and industrial heat; for the production of hydrogen, to be used as a fuel; the generation of electricity; and, the production of fissile material for fission nuclear reactors.

Fusion Reactor Configurations — Closed Magnetic Confinement

Figure 24 SCHEMATIC REPRESENTATION OF A TOKAMAK REACTOR



Source: After *The Princeton University Plasma Laboratory: An Overview*, 1979, p. 8.

The fusion reactor configuration with the longest history of development is the Tokamak, named after a device with which the Russians did some pioneering research on plasma stability. The Tokamak involves closed magnetic confinement of a plasma in a torus (doughnut-shaped chamber) maintained at a high vacuum. Three different magnetic fields, or sets of fields, act to confine the plasma within the torus or vacuum vessel. The toroidal magnetic field is the basic confining field, and the poloidal field forces the plasma toward the middle of the torus. To maintain plasma equilibrium and stability, a third set of magnetic fields is generated by smaller coils along the periphery of the torus.

Various means can be used to add energy to the plasma. In the Princeton TFTR (Tokamak Fusion Test Reactor) pictured above, high-energy, neutral-particle beams will carry energy into the plasma and provide the extra heat required to reach ignition temperature. To give an idea of scale, the torus or vacuum chamber for TFTR will be 1.7 metres in diameter and almost 8 metres across. TFTR is designed to achieve scientific breakeven and is scheduled to be operational in 1982.

However the potential of this energy source has not sufficiently developed at this point in time. Answers to the question--Is magnetic fusion practical in terms of engineering, economics and safety?--have not yet been determined. Fusion power, therefore will not be considered as a viable alternative energy source for the forseeable future.

District Heating

District heating is not an alternate energy source but a means to effectively distribute this energy. Space heat, in the form of hot water or steam, is generated at a central location; in Gypsumville's case a central heating plant, and then distributed through a system to the end users. The alternate energy forms would be the heat source. Another aspect of this technology that is gaining popularity is co-generation. This case involves the waste heat that is produced by the generation of electricity being distributed as space heat. In reality, CFS Gypsumville minus the PMQ's, was heated and powered via a co-generation central heating and power plant.

District heating has seen widespread use in the Soviet Union and Europe since the 1950's. However, it is not as popular in North America. For alternate energy systems, one of the major costs is that for storage systems. Economies of scale are one advantage of district heating schemes. The heat source is at one central location thus reducing the cost of producing heat. The storage facility can be centrally located, thus reducing its overall size, heat losses and most important its cost. This is important since the lower the cost of the alternate energy system the better the chance of it being used to replace the existing fossil fuels.

Summary

This chapter has outlined the importance of energy in this industrialized world. With the increasing price of fossil fuels, especially crude oil (ignoring the present and likely transient dip in the cost price) and the diminishing reserves, the world has looked to renewable forms of energy as viable alternatives. These sources include solar, wind, biomass, geothermal, and nuclear energy.

The majority of alternate energy forms discussed would be suitable sources of supply for the heating and electrical energy requirements of the Station. Those not considered viable at this time would be geothermal energy, fusion energy and most forms of biomass except for wood, Municipal Solid Waste and sewage. At this juncture economics have not been taken into account in the assessment of the different energy forms. This analysis will be carried out in Chapter 4.

Fusion energy is not anticipated to be a viable alternate source until well into the 21 st century when, at that time, it will be utilized on a very large scale with power outputs approaching one to two thousand megawatts. Geothermal energy will also be used in the future, however it has the potential to be used on a small or large scale depending upon the its intended use. Technology is available now to utilize this energy but it would not be used until the price of oil reached and exceeded its previous high levels of $45.00 per barrel. Other forms of biomass not mentioned, for example water hyacinth and sea weed, can be used but not in Canada as they are not available.

The present and future potential for alternate energy generation has previously been presented in Table 1 of Chapter 1 but is reprinted here as it is pertinent to the concluding remarks to this chapter. There are many installations of the various technologies with the majority being photovoltaics and wind systems; however when comparing the actual output (1985) with the installations, the applications are on a very small scale. The greatest expansion is wind technology with an increase in output of over 800 % , from 6 MW to 50 MW. This table supports the premise of Ontario Hydro that in remote areas, wind for 8.6 cents /kWh and 7.1 cents for photovoltaics, are more economic than diesel generation for 9.5 cents/kWh (reported in SOL Vol 55 Sept-Oct 1986 pg 15).

From the above analysis the forms of alternate energy that can be utilized are listed in order of viability, from most to least likely:

(1) Nuclear energy in the form of the SLOWPOKE Reactor;

(2) Direct combustion of Wood and MSW;

(3) Wind;

(4) Solar energy including Photovoltaics;

(5) Geothermal energy; and,

(6) Nuclear fusion

Table 1 Canadian Alternative Energy Generation: (1985-1995)

Technology	Installations 1985 (actual)	Installations 1995 (expected)	Output (MW) 1985 (actual)	Output (MW) 1995 (expected)	Applications
Private Hydroelectric	200	400	882	1042	*Private and Municipal development *Remote community power
Wind	600	1000	6	50	*Small Scale independent systems *Remote community Power
Cogeneration (Incl biomass)	344	1000	1200	3500	*Industrial and Institutional
Municipal Solid Waste	5	15	4	15	*District Heating *Municipal and industrial
Photovoltaics	2100	4000	0.1	1	*Off grid, power applications *Remote community power

Source: Data provided by the Department of Energy, Mines and Resources (Canada), the provincial governments and major utilities across Canada.

AUTONOMOUSLY SERVICED SETTLEMENTS

CHAPTER THREE

CANADIAN FORCES STATION GYPSUMVILLE

Canadian Forces Station (CFS) Gypsumville has been chosen as the case study because it is considered to be a typical isolated community and that it parallels those features found in many small mining towns, remote northern communities and Indian reservations. It is relatively isolated, its population is small, there is housing available, an industrial and administration area, a recreation complex and retail stores. Factual data on the site characteristics are readily available and the station is accessible simplifying the collection of data. Conversely, a fictitious community does not have to be created in order to prove the hypothesis.

GENERAL DESCRIPTION [78]

CFS Gypsumville is classified as a heavy radar site that forms part of the Pinetree Line controlled by Air Command. The unit is designated a NORAD surveillance site operationally controlled from Canadian Forces Base (CFB) North Bay. CFS Gypsumville was constructed in 1961/62 which made it the last of the new generation radar sites to be built in Western Canada.

CFS Gypsumville is located on approximately 800 acres of land in the interlake region of Manitoba 155 road miles north-west of Winnipeg on Provincial Highway No. 6 just south of the 52 nd. parallel. The unit consists of two areas separated by one-quarter of a mile. The operational area, containing the radar domes and its associated

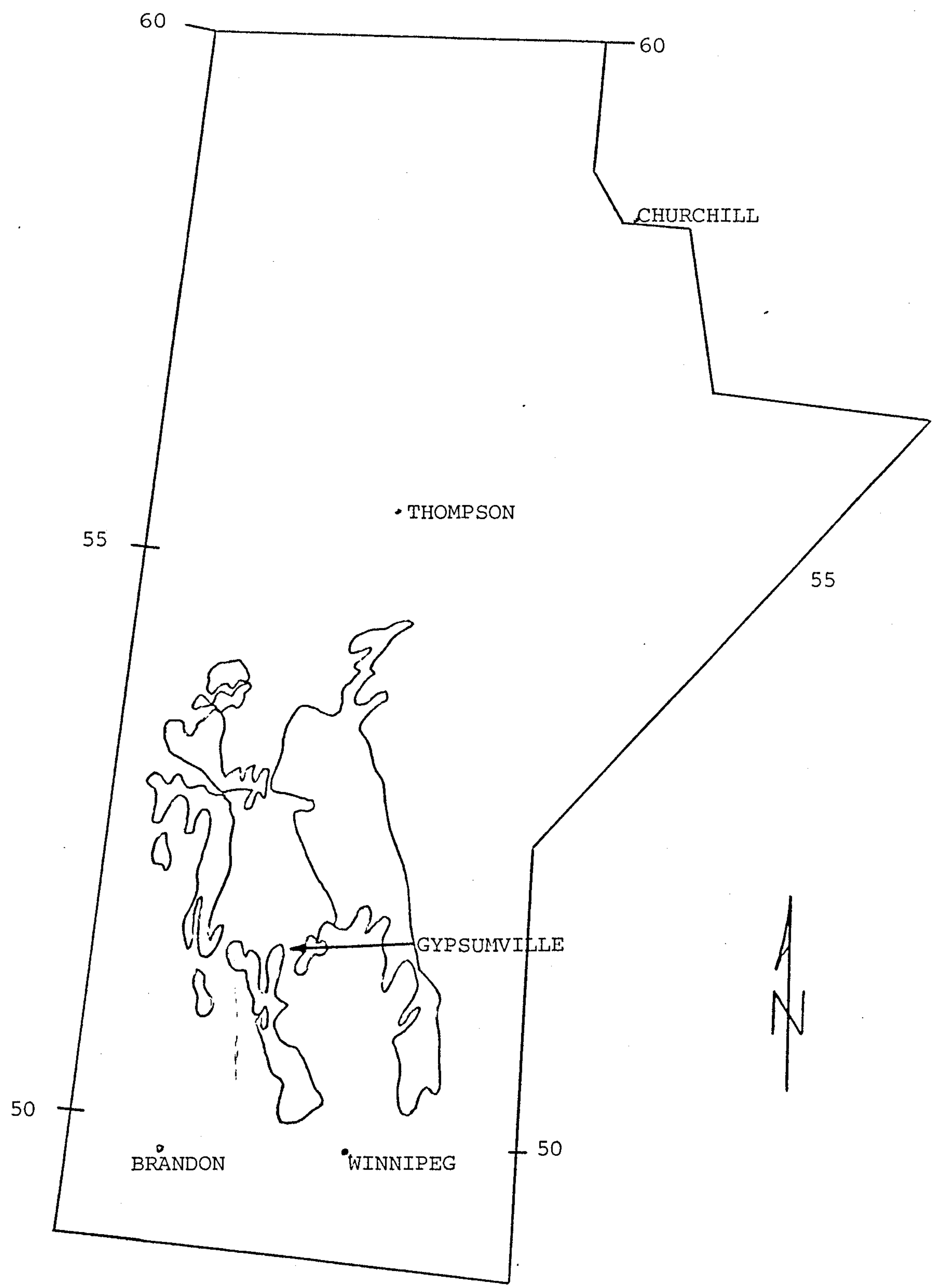


Figure 25: Location of Gypsumville in the Province of Manitoba

support facilities and buildings, is on the west side of Hwy 6. The domestic (residential) and industrial area containing married quarters, administration and the industrial complex, is on the east side of the highway.

Generally CFS Gypsumville is forced to be a self-contained community due to its isolation from major urban areas, with Winnipeg being the closest major centre. To the north, the only major settlement served by an all-weather road is Thompson, some 250 miles away. Figure 25 depicts the province of Manitoba showing the Station in relation to the other prominent areas.

Location

CFS Gypsumville is located on Highway No. 6 between Lake Manitoba and Lake Winnipegosis about 5 miles north of the Fairford River. The small villages of Fairford, Gypsumville and St Martins are in the same vicinity along with three Indian reservations belonging to the Saulteaux tribes. Canadian National Railways has a rail line just east of the station running north-south. Running parallel to this rail line is a Manitoba Hydro transmission power line (2 lines, one of which is a high voltage DC line).

The station consists of 800 acres of land described in the Lands Title office as follows:

1. NE 1/4 Sec18, TWP 31, R9, WPM 160.0 acres

2. NW1/4 Sec18 and SW1/4 Sec 19, TWP 31 R9, WPM excepting out of both 1/4 sections the most W 67' in perpendicular width. — 313.9 acres

3. NE1/4 Sec 13, TWP 31, R10, WPM excepting the most E 67' in perpendicular width. — 156.94 acres

4. NE 1/4 Sec 14. TWP 31, R10. — 160.0 acres

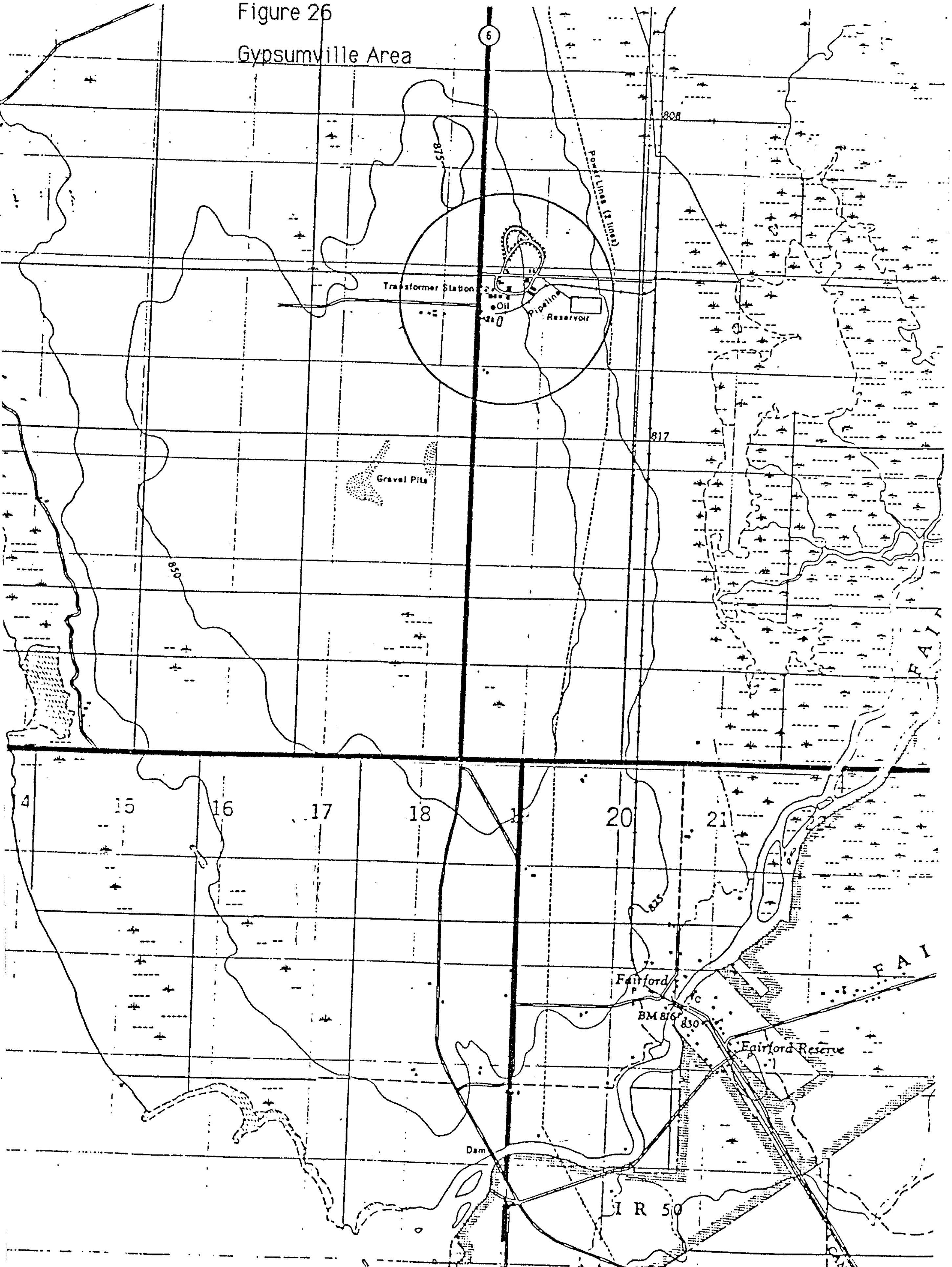
Figure 26 shows the Station in relation to the above and the nearby areas. The area in Township (TWP) 31 includes 21 acres for the MQ area and 65 acres comprising the Industrial, Administration and Recreational area.

Topography and Climate

The area surrounding Gypsumville (hereafter known as the Station) is generally level and heavily treed with dense scrub growth. The geology of the area (Manitoba is in the central platform area, western Canada sedimentary basin, of the Prairies) is shattered limestone which varies in depth from 6 inches to 8 feet below the surface. Top soil is thin, usually with a hard clay formation directly below the top soil. The area has an abundance of water nearby with the Fairford River running east-west to Lake Winnipeg, just five miles south of the station. Generally the area has marshy conditions in many locations due to insufficient drainage.

Figure 26

Gypsumville Area



MANITOBA/MANITOBA

GYPSUMVILLE
51° 40′N 98° 44′W 265 m

	JAN JAN	FEB FÉV	MAR MAR	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOÛT	SEP SEPT	OCT OCT	NOV NOV	DEC DÉC	YEAR ANNÉE	CODE CODE	
Daily Maximum Temperature	−15.3	−10.6	−2.6	7.9	16.5	21.3	23.9	22.3	16.7	8.7	−1.7	−11.1	6.3	8	Température Maximale Quotidienne
Daily Minimum Temperature	−26.0	−22.9	−14.8	−4.2	3.5	8.8	12.0	10.2	5.6	−0.2	−9.8	−21.1	−4.9	8	Température Minimale Quotidienne
Daily Temperature	**−20.7**	**−16.8**	**−8.7**	**1.9**	**10.1**	**15.1**	**18.0**	**16.3**	**11.1**	**4.3**	**−5.8**	**−16.1**	**0.7**	**8**	**Température Quotidienne**
Standard Deviation, Daily Temperature	2.8	3.3	3.1	3.0	2.9	1.6	1.7	1.8	1.8	1.8	2.2	3.6	0.8	5	Écart Type de la Température Quotidienne
Extreme Maximum Temperature	6.7	7.5	16.1	32.5	30.9	33.3	34.6	33.5	35.6	23.9	18.9	7.8	35.6		Température Maximale Extrême
Years of Record	13	14	15	15	14	14	14	14	14	14	14	13			Années de Relèves
Extreme Minimum Temperature	−42.8	−42.8	−34.4	−27.8	−11.7	−3.3	0.0	−1.0	−5.0	−15.0	−32.4	−40.6	−42.8		Température Minimale Extrême
Years of Record	15	14	15	15	14	14	14	14	14	14	14	13			Années de Relèves
Rainfall	0.2	0.8	1.2	9.5	32.8	58.7	63.6	63.6	51.4	18.4	1.3	0.0	301.3	8	Chutes de Pluie
Snowfall	20.0	13.5	18.6	7.6	1.5	0.1	0.0	0.0	0.1	3.2	17.8	19.7	102.1	8	Chutes de Neige
Total Precipitation	**22.1**	**13.8**	**18.9**	**17.3**	**34.0**	**58.8**	**63.6**	**63.6**	**51.3**	**25.1**	**25.9**	**24.0**	**418.4**	**8**	**Précipitations Totales**
Standard Deviation, Total Precipitation	14.4	7.2	17.5	16.9	34.6	32.5	22.6	35.2	37.8	30.5	13.8	10.1	87.1	5	Écart Type des Précipitations Totales
Greatest Rainfall in 24 hours	0.5	2.5	13.0	28.4	55.1	32.1	81.3	42.4	74.9	31.0	5.0	T	81.3		Chute de Pluie Record en 24 heures
Years of Record	12	15	15	14	12	14	14	14	14	14	14	12			Années de Relèves
Greatest Snowfall in 24 hours	23.1	9.9	32.5	21.8	6.4	1.0	0.0	0.0	1.5	20.6	15.7	18.8	32.5		Chute de Neige Record en 24 heures
Years of Record	12	15	15	14	13	14	14	14	14	14	14	13			Années de Relèves
Greatest Precipitation in 24 hours	23.1	9.9	32.5	28.4	55.1	32.1	81.3	42.4	74.9	31.0	15.7	18.8	81.3		Précipitation Record en 24 heures
Years of Record	12	15	15	14	12	14	14	14	14	14	14	13			Années de Relèves
Days with Rain	0	0	0	2	6	9	9	8	7	4	1	0	46	8	Jours de Pluie
Days with Snow	7	5	5	2	1	0	0	0	0	1	6	7	34	8	Jours de Neige
Days with Precipitation	7	5	5	4	6	9	9	8	7	5	7	7	79	8	Jours de Précipitation

Gypsumville is situated on latitude 51 degrees 40' N, 98 degrees 44' W at an elevation of 265 metres. It experiences a moderate climate, averaging 1200 degree days Celcius with a January mean temperature of -20.7'C and a July mean temperature temperature of 18'C. Solar radiation data is not available but it would approximate Winnipeg's i.e. 5800 MJ/m^2 per year on a collector inclined at 65 degrees. Table 6 illustrates the climate details.

Station Facilities

As stated previously the Station consists of two areas separated by one-quarter of a mile and Hwy 6: the Operations area; and, the Residential area. The residential site can be further delineated into four areas or, per zones; residential, industrial, recreational and administration.

The residential zone consists of 91 Department of National Defence (DND) three and four bedroom double wide trailer units averaging 1000 sq. ft. in area; plus 25 privately owned trailer pads, and six DND trailers (12 feet by 60 feet). Figure 27 shows the specific details of one typical double wide trailer unit (hereafter known as Married Quarters-MQs). Figure 28 details the various physical components of the station including utilities, commonly called Works.

CANADIAN FORCES FORCES CANADIENNES

CONSTRUCTION ENGINEERING MANAGEMENT INFORMATION SYSTEM (CEMIS)
SYSTÈME INTÉGRÉ DE GESTION – GÉNIE CONSTRUCTION (SIGGC)

MARRIED QUARTERS — LOGEMENTS FAMILIAUX

LEGEND: PRIN – PROPERTY RECORD IDENTIFICATION NUMBER
CRPI – CENTRAL REAL PROPERTY INVENTORY

LEGENDES: NITP – NUMÉRO D'IDENTIFICATION DES TITRES DE PROPRIÉTÉ
RCBI – RÉPERTOIRE CENTRAL DES BIENS IMMOBILIERS

CF/A 303 (12-75)

DATE PREP AMEND / PRÉP MODIF (A03)	REPORT – RAPPORT DATE	PAGE (A04)
09 FEB 85	09 FEB 85	1 OF/DE 1

PRIN – NITP (A01)	(C01)	LOCATION – GÉOGRAPHIQUE CODE (C02)	PLACE NAME – NOM DU LIEU	PROVINCE (C03)
Q40967	BLDG NO PMQ 32	G136	GYPSUMVILLE	MAN

CE SUPPORT BASE U/C / CIU-BASE DE SOUTIEN TB (C04)	NAME – NOM	FUNCT. COMM. – COMM. FONCT. (C05)	CRPI CODE – CODE DE RCBI (C09)
2399	CANADIAN FORCES STATION GYPSUMVILLE	AIR COMMAND	461806007012932

FACILITY NAME – NOM DE L'INSTALLATION (C06)	SITE CLASS. – CAT. DU SITE (C07)	REG. ADDRESS – ADRESSE RÉG. (C08)	
TRHM	SEMI-URBAN	RPO PRAIRIE	WARNING-LIFE EXPCT. INCONSISTENT WITH DEV. CATEGORY

NAME OF LESSOR (IF LEASED) / NOM DU BAILLEUR LOCATION À BAIL (D01)	REF. PRIN / NITP REF. (D02)	YEAR – ANNÉE (D03)	HERITAGE BLDG / BÂT. HISTORIQUE (D04)	BLDG. DRWG. NO. / NO DU PLAN DU BÂT. (D05)	CRPI CATEGORY / CATÉGORIE DU RCBI
		CONSTRUCTED 1963 A	NO	L G136 7000	RES

ORIG. CAPITAL COST / FRAIS INIT. IMMOB. (D06)	EST. REP. COST / COÛT EST. REMP.	DATE EST. PREP / DEVIS EST. PRÉP. LE	LIFE EXPECTANCY / DURÉE UTILE PRÉVUE (D07)	DEV. CAT. / CATÉGORIE D'AMÉNAGEMENT (D08)	FUNCT. SUITABILITY / VALEUR FONCTIONNELLE (D09)	BUILDING – STRUCTURE CLASS. – CAT. (D10)	QUALITY – QUALITÉ (D11)
$29,000 E	$64,757	09 JUL 84	1990	A MR= A	GOOD	D	FAIR

AREA (SQ. FT.) – SUPERFICIE (PI. CAR.) GROSS – TOTALE (D12)	LIVING – HABITABLE (D13)	BASEMENT / SOUS-SOL (D14)	STORAGE / ENTREPOSAGE (D15)	GARAGE (D16)	NO. OF STOREYS / NOMBRE D'ÉTAGES (D17)	PAINTABLE SURFACES (SQ. FT.) – SURFACES PEINTURABLES (PI. CAR.) EXTERIOR – EXTÉRIEUR (D18)	INTERIOR – INTÉRIEUR (D19)
1,248	1,119		129		1.5	1,438	206

MODEL / MODÈLE (D20)	TYPE (D21)	NO. OF ROOMS / NOMBRE DE PIÈCES (D22)	NO. OF BEDROOMS / NOMBRE DE CHAMBRES (D23)	FUEL – COMBUSTIBLE TYPE (D24)	CONDITION OF BUILDING SERVICES – EFFICACITÉ DES SERVICES UTILITAIRES: ELECTRICAL – ÉLECTRICITÉ (D25)	HEATING – CHAUFFAGE (D26)	PLUMBING – PLOMBERIE (D27)	FIRE PROTECTION / PROT. INCENDIES (D28)
C	SINGLE	7	4	OIL	GOOD	GOOD	GOOD	FAIR

ASSESSED MONTHLY RENTAL – LOYER MENSUEL AMOUNT – MONTANT (D29)	DATE OF LAST ASSMT. / DATE DE LA DERN. FIXATION (D30)	DATE VACATED (IF VACANT) / ÉVACUÉ LE (SI LIBRE) (D31)	COST OF DND SUPPLIED UTILITIES (PER MONTH) – COÛT DES SERVICES FOURNIS PAR LE MDN (PAR MOIS): ELECTRICITY – ÉLECTRICITÉ (D32)	HEAT – CHAUFFAGE (D33)	WATER – EAU (D34)	TOTAL
$173.00	01 NOV 84		$37.48	$46.88	$9.39	$93.75

SPECIAL INFORMATION – RENSEIGNEMENTS SPÉCIAUX (E01)

01190 SQ FT CARPORT

PRIN – NITP	LOCATION – LIEU	ADDRESS OR BUILDING NUMBER – ADRESSE OU NUMÉRO DU BÂTIMENT	
Q40967	GYPSUMVILLE	PMQ 32	F00623

CONSTRUCTION ENGINEERING MANAGEMENT INFORMATION SYSTEM

FACILITIES CATALOGUE - WORKS

BASE: CANADIAN FORCES STATION GYPSUMVILLE
LOCATION: GYPSUMVILLE
FUNCTIONAL COMMAND: AIR COMMAND
SITE CLASS: SEMI URBAN

CURRENT DESIGNED USE	FACILITY NAME	CAPACITY	MATERIAL	CONS /ACQ	YEAR	ACT /EST	STRUCTURE CLASS	STRUCTURE QUAL	LIFE EXP	DEV CAT
AIRSTRIPS	GRAVEL AIRSTRIP-TA		GRAVEL	C	1973	A	C	A	1990	C
ANTENNAE FARM	ANTENNA FARM-TA		METAL	C	1962	E	C	A	1990	A
BALL DIAMOND	SOFTBALL DIAMOND MQA			C	1962	E	C	G	1990	A
BALL DIAMOND	SOFTBALL DIAMOND MQA			C	1966	E	B	G	1990	A
BLEACHERS	2 BLEACHERS-MQA	60 SEATS	WOOD	C	1970	E	C	F	1990	A
BRIDGE, STEEL	CULVERT 16 FEET LONG	TONS	METAL	C	1962	E	C	G	1990	A
BRIDGE, STEEL	CULVERT 26 FEET LONG	TONS	METAL	C	1962	E	C	G	1990	A
BRIDGE, STEEL	CULVERT 50 FEET LONG	TONS	METAL	C	1962	E	C	G	1990	A
BRIDGE, STEEL	CULVERT 75 FEET LONG	TONS	METAL	C	1962	E	C	G	1990	A
ELC DIS SYS BELOW 2400V	STN&PMQ DISTRIBUTION	VOLTS		C	1962	A	B	G	1990	A
ELECTRICAL GENERATION	GATR SITE-TA	300 KW		C	1962	A	B	G	1990	A
ELECTRICAL SUBSTATION	STANDBY POWER-BAA	2250 KVA		C	1962	A	B	G	1990	A
ELECTRICAL SUBSTATION	SUB STATION -POWER SYSTEM -BAA	198 KVA		C	1962	A	B	G	1990	A
FENCE, CHAIN LINK	OUTER FENCE-BAA		METAL	C	1962	A	C	A	1990	A
FENCE, OTHER	FENCING		WOOD	C	1973	E	C	A	1990	A
FIRE ALARM SYSTEM	FIRE ALARM BOXES-BAA&MQA&TA	25 CALL BOXES	WOOD	C	1962	A	B	G	1990	A
FIRE ALARM SYSTEM	FIRE DETECTORS	1 CALL BOXES	METAL	C	1962	A	B	G	1990	A
FIREGUARD	FIREBREAK-BAA			C	1962	E	B	A	1990	A
GOLF COURSE	GOLF COURSE-BAA	9 HOLES		C	1973	A	C	A	1990	A
HOCKEY RINK (OUTDOOR)	SKATING RINK-BAA		WOOD	C	1972	A	C	A	1985	A

CONSTRUCTION ENGINEERING MANAGEMENT INFORMATION SYSTEM

FACILITIES CATALOGUE - WORKS

BASE: CANADIAN FORCES STATION GYPSUMVILLE
LOCATION: GYPSUMVILLE
FUNCTIONAL COMMAND: AIR COMMAND
SITE CLASS: SEMI URBAN

CURRENT DESIGNED USE	FACILITY NAME	CAPACITY	MATERIAL	CONS /ACQ	YEAR	ACT /EST	STRUCTURE CLASS	STRUCTURE QUAL	LIFE EXP	DEV CAT
HTNG DIS SYS, UNDERGRND	U.G. HEAT DIST. LINES-BAA		METAL	C	1962	A	C	A	1990	A
HTNG PRODN, OVER 200HP	CHP BOILERS(2)-BAA	400 HP	METAL	C	1962	A	C	A	1990	A
HTNG PRODN, OVER 200HP	WASTE HEAT GENERATORS(3)-BAA	1440 HP	METAL	C	1962	A	C	A	1990	A
HTNG PRODN, 0-200HP	STEAM BOILERS(2)-BAA	100 HP	METAL	C	1962	A	C	A	1990	A
IMPROVED GROUNDS GRASSD	HELIPAD-TA			C	1962	E	B	G	1990	A
IMPROVED GROUNDS GRASSD	IMPROVED GROUNDS-BAA			C	1962	E	C	G	1990	A
IMPROVED GROUNDS GRASSD	IMPROVED GROUNDS-MQA			C	1962	E	C	G	1990	A
INCINERATOR	INCINERATOR-BAA	LBS/HR	METAL	C	1970	A	D	A	1985	A
LOADING RAMP, CONC.	LOADING RAMP-CONC. BAA	TONS	CONCRETE	C	1962	E	D	G	1990	A
MAST	MAST BAA		WOOD	C	1962	E	C	G	1990	A
MAST	MAST BAA		WOOD	C	1962	E	C	G	1990	A
MAST	MAST BAA		WOOD	C	1962	E	C	G	1990	A
PAVED PARKING AREA	PAVED PARKING AREAS-BAA		ASPHALT	C	1974	A	B	G	1982	A
PAVED ROAD, ASPH.	PAVED MAIN ROADS-BAA		ASPHALT	C	1974	A	C	A	1990	A
PAVED ROAD, ASPH.	PAVED MAIN ROADS-MQA		ASPHALT	C	1974	A	C	A	1990	A
POL RESERVOIR	OIL STORAGE TANKS(2)-BAA	105 M GALS	METAL	C	1962	A	C	A	1990	A
SAN SEWAGE COLLECTN SYS	SEWAGE COLLECTION MAIN-BAA		METAL	C	1962	A	C	A	1990	A
SAN SEWAGE COLLECTN SYS	SEWAGE COLLECTION MAIN-MQA		METAL	C	1962	A	C	A	1990	A
SEWAGE LAGOON	SEWAGE LAGOON-BAA			C	1962	A	C	A	1990	A
SIREN	CFWRS SIREN -BAA	11 HP	METAL	C	1973	A	A	G	1995	A

LBMKHP. *DIST A-B(2)-C-L-2399(2)

CONSTRUCTION ENGINEERING MANAGEMENT INFORMATION SYSTEM

FACILITIES CATALOGUE - WORKS

BASE: CANADIAN FORCES STATION GYPSUMVILLE
LOCATION: GYPSUMVILLE
FUNCTIONAL COMMAND: AIR COMMAND
SITE CLASS: SEMI URBAN

CURRENT DESIGNED USE	FACILITY NAME	CAPACITY	MATERIAL	CONS /ACQ	YEAR	ACT /EST	STRUCTURE CLASS	STRUCTURE QUAL	LIFE EXP	DEV CAT
SKI HILL	TOBOGGAN SLIDE MQA	TOW SEATS		A	1962	E	C	A	1995	A
SWIMMING AREA	SWIMMING AREA		GRAVEL	A	1962	E	C	A	1990	A
SWIMMING AREA	SWIMMING POOL		CONCRETE	C	1970	A	C	G	1995	A
	REMARKS: OUTDOOR SWIMMING POOL SUPPLIED FROM REC CENTRE									
SWIMMING AREA	WADING POOL		CONCRETE	C	1976	A	C	A	1990	A
TRAILER PAD	TRAILER PADS-MQA	6 PADS	CONCRETE	C	1971	E	C	A	1990	A
TRAILER PAD	25 TRAILER PADS	25 PADS	GRAVEL	C	1969	E	C	A	1991	A
TWENTY-FIVE YARD RANGE	PISTOL RANGE-TA			C	1967	A	C	F	1985	A
UNIMPROVED GROUNDS	UNIMPROVED GROUNDS-BAA			C	1962	E	C	A	1990	A
UNPAVED ROAD	SECONDARY ROADS-BAA		GRAVEL	C	1962	A	C	F	1990	A
UNPAVED ROAD	SECONDARY ROADS-MQA		GRAVEL	C	1962	A	C	F	1990	A
UNPAVED ROAD	SECONDARY ROADS-TA		GRAVEL	C	1962	A	C	F	1990	A
WATER DISTRIBUTION SYS	UG WATER DIST LINES-BAA		METAL	C	1962	A	C	A	1990	A
WATER DISTRIBUTION SYS	WATER DIST LINES-MQA		METAL	C	1962	A	C	A	1990	A
WATER RESERVOIR	WATER STORAGE TANKS	200 M GALS	CONCRETE	C	1962	A	C	A	1990	A
WELL	WELL-BAA	346 M GALS/DAY	METAL	C	1962	A	C	A	1990	A

CANADIAN FORCES   FORCES CANADIENNES

CONSTRUCTION ENGINEERING MANAGEMENT INFORMATION SYSTEM (CEMIS)
SYSTÈME INTÉGRÉ DE GESTION – GÉNIE CONSTRUCTION (SIGGC)

LEGEND: PRIN – PROPERTY RECORD IDENTIFICATION NUMBER
CRPI – CENTRAL REAL PROPERTY INVENTORY

LEGENDES. NITP – NUMÉRO D'IDENTIFICATION DES TITRES DE PROPRIÉTÉ
RCBI – RÉPERTOIRE CENTRAL DES BIENS IMMOBILIERS

MARRIED QUARTERS — LOGEMENTS FAMILIAUX

CF/A 303 (12-75)

DATE PREP AMEND / PREP MODIF (A03)	REPORT – RAPPORT DATE	PAGE (A04)
09 FEB 85	09 FEB 85	1 OF/DE 1

PRIN – NITP (A01)	Q40967
(C01)	BLDG NO PMQ 32
LOCATION – GÉOGRAPHIQUE CODE (C02)	G136
PLACE NAME – NOM DU LIEU	GYPSUMVILLE
PROVINCE (C03)	MAN
CE SUPPORT BASE U/C – CIU-BASE DE SOUTIEN TB (C04)	2399
NAME – NOM	CANADIAN FORCES STATION GYPSUMVILLE
FUNCT. COMM. – COMM. FONCT. (C05)	AIR COMMAND
CRPI CODE – CODE DE RCBI (C09)	461806007012932
FACILITY NAME – NOM DE L'INSTALLATION (C06)	TRHM
SITE CLASS. – CAT. DU SITE (C07)	SEMI-URBAN
REG. ADDRESS – ADRESSE RÉG. (C08)	RPO PRAIRIE
	WARNING-LIFE EXPCT. INCONSISTENT WITH DEV. CATEGORY

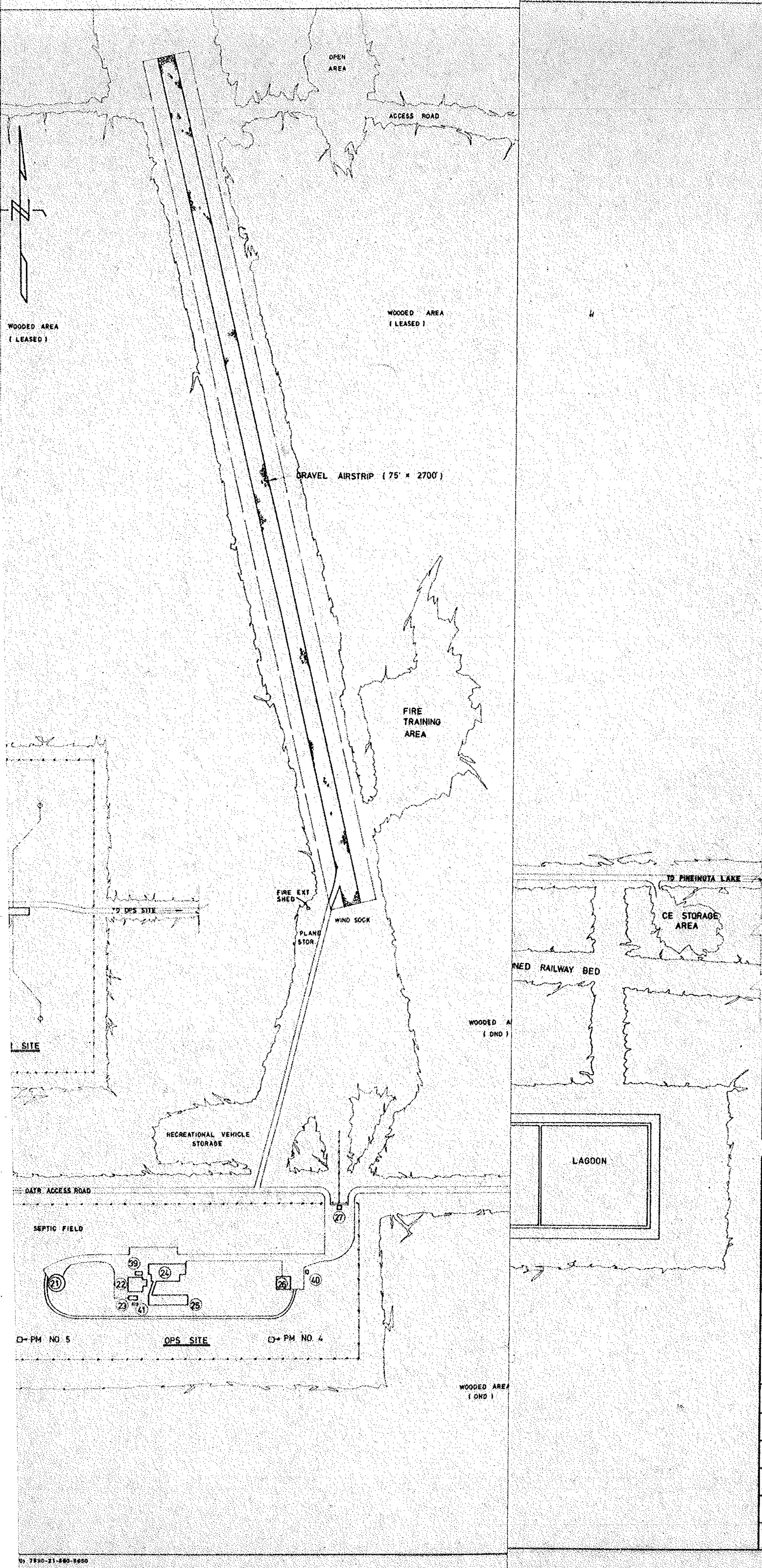
NAME OF LESSOR (IF LEASED) – NOM DU BAILLEUR (LOCATION À BAIL) (D01)	
REF PRIN – NITP REF. (D02)	
YEAR – ANNÉE (D03)	CONSTRUCTED 1963 A
HERITAGE BLDG – BÂT. HISTORIQUE (D04)	NO
BLDG. DRWG. NO. – NO DU PLAN DU BÂT. (D05)	L G136 7000
CRPI CATEGORY – CATÉGORIE DU RCBI	RES
ORIG. CAPITAL COST – FRAIS INIT. IMMOB. (D06)	$29,000 E
EST. REP. COST – COÛT EST. REMP.	$64,757
DATE EST. PREP – DEVIS EST. PRÉP. LE	09 JUL 84
LIFE EXPECTANCY – DURÉE UTILE PRÉVUE (D07)	1990
DEV. CAT. – CATÉGORIE D'AMÉNAGEMENT (D08)	A MR= A
FUNCT. SUITABILITY – VALEUR FONCTIONNELLE (D09)	GOOD
BUILDING – STRUCTURE CLASS – CAT. (D10)	D
QUALITY – QUALITÉ (D11)	FAIR
AREA (SQ. FT.) – SUPERFICIE (PI. CAR.) GROSS – TOTALE (D12)	1,248
LIVING – HABITABLE (D13)	1,119
BASEMENT – SOUS-SOL (D14)	
STORAGE – ENTREPOSAGE (D15)	129
GARAGE (D16)	
NO. OF STOREYS – NOMBRE D'ÉTAGES (D17)	1.5
PAINTABLE SURFACES (SQ. FT.) – SURFACES PEINTURABLES (PI. CAR.) EXTERIOR – EXTÉRIEUR (D18)	1,438
INTERIOR – INTÉRIEUR (D19)	206
MODEL – MODÈLE (D20)	C
TYPE (D21)	SINGLE
NO. OF ROOMS – NOMBRE DE PIÈCES (D22)	7
NO. OF BEDROOMS – NOMBRE DE CHAMBRES (D23)	4
FUEL – COMBUSTIBLE TYPE (D24)	OIL
CONDITION OF BUILDING SERVICES – EFFICACITÉ DES SERVICES UTILITAIRES: ELECTRICAL – ÉLECTRICITÉ (D25)	GOOD
HEATING – CHAUFFAGE (D26)	GOOD
PLUMBING – PLOMBERIE (D27)	GOOD
FIRE PROTECTION – PROT. INCENDIES (D28)	FAIR
ASSESSED MONTHLY RENTAL – LOYER MENSUEL AMOUNT – MONTANT (D29)	$173.00
DATE OF LAST ASSMT. – DATE DE LA DERN. FIXATION (D30)	01 NOV 84
DATE VACATED (IF VACANT) – ÉVACUÉ LE (SI LIBRE) (D31)	I
COST OF DND SUPPLIED UTILITIES (PER MONTH) – COÛT DES SERVICES FOURNIS PAR LE MDN (PAR MOIS): ELECTRICITY – ÉLECTRICITÉ (D32)	$37.48
HEAT – CHAUFFAGE (D33)	$46.88
WATER – EAU (D34)	$9.39
TOTAL	$93.75

SPECIAL INFORMATION – RENSEIGNEMENTS SPÉCIAUX (E01)

01190 SQ FT CARPORT

PRIN – NITP	LOCATION – LIEU	ADDRESS OR BUILDING NUMBER – ADRESSE OU NUMÉRO DU BÂTIMENT
Q40967	GYPSUMVILLE	PMQ 32

F00623



BLDG LEGEND

1	REC CENTER
1a	CURLING CLUB
2	POWER PLANT
3	HQ & MIR
4	MT & SUPPLY
5	SCEO & FIREHALL
6	CO-ED BARRACKS
7	COMBINED MESS
8	GUARD HOUSE
8a	GATE HOUSE
9	WATER TREATMENT
10	HOBBY CLUB
11	CHAPEL
12	DND SCHOOL
13	OIL PUMPHOUSE
14	SEWAGE LIFT STN
21	FPS 507
22	FPS 27
23	FPS 27 TOWER
24	TECH ANNEX
25	SAGE ANNEX
26	FPS 26
27	GATE HOUSE
28	GATR
29	LUMBER STORAGE
30	ICE RINK LODGE
31	AUTO CLUB
32	CANEX
33	CHLORINE STORAGE
34	FIRING SHELTER
35	STOR SHED - SGTS.
36	" " - OFFC.
37	" " - JRC.
38	" " - CANEX
39	" " - 27 TWR
40	" " - 26 TWR
41	STORAGE - STEAM JEN.
42	CE STORAGE SHED
42a	" " "
43	" " "
44	" " "
45	" " "
46	CE STORAGE SHED
47	POL BULK STORAGE
56	BULK STORAGE
68	BULK STORAGE
85	BULK STORAGE

NO.	DATE	DESCRIPTION	DRAWN BY DESSINÉ PAR	APP'D. BY APPR. PAR
1	22-01-82	ENTIRE DWG UPDATED & REDRAWN	GSM	

REVISION — RÉVISION

DEPARTMENT OF NATIONAL DEFENCE
MINISTÈRE DE LA DÉFENSE NATIONALE
STATION CONSTRUCTION ENGINEERING SECTION

PROJECT & LOCATION — PROJET ET EMPLACEMENT
SITE PLAN
CFS GYPSUMVILLE

TRADE — MÉTIER
SITING

SUBJECT — SUJET
FIGURE 29

PRODUCTION | CONCURRENCE — APPROBATION

DESIGNED BY — ÉTUDIÉ PAR
DRAWN BY — DESSINÉ PAR GSM
CHECKED BY — VÉRIFIÉ PAR GSM
SFC
DATE 82-01-22
APPROVED BY — APPROUVÉ PAR SCEO
SCALE — ÉCHELLE 1" = 200'
DWG. NO. — DESSIN NO. L - G136 - 8420 - 102

7530-21-880-8660

The administration area consists of a headquarters complex, a small hospital, Military Police guardhouse and gatehouse, two churches and a six wing building containing single quarters. The industrial area consists of a power plant, Petroleum, Oils and Lubricants (POL) tank farm, water and sewage treatment plants, two large complexes providing engineering, supply and transport services (can be compared to the city of Winnipeg's Works and Operations department), a small retail outlet, post office and service station totalling 25,000 sq. ft. in building area. The recreational area consists of a recreation centre complex including gymnasium and bowling alley, outdoor swimming pool, outdoor skating rink, two sheet curling rink and a nine hole golf course. Figure 29 details the layout of the Station.

The Operations area consists of three radar tower complexes, one radio/receiver site (GATR) and a 2800 by 50 foot gravel airstrip. Being sensitive in nature no further mention of this site will be made in this thesis.

Essentially CFS Gypsumville is a self-contained community in a relatively isolated and sparsely populated area of the Interlake region of Manitoba. It is, in fact, an ideal location for a sensitive military installation. When it opened in 1962, it was an autonomously serviced settlement. It did however require diesel fuel to operate its power plant. Therefore it was not autonomous in the strictest sense of the word as it did not produce its own food and had to bring in fuel to run its power and heating plants.

CFS Gypsumville has been chosen as the case study because it is a small community that compares favourably to most small remote towns. It parallels those features found in many small mining towns, remote northern communities and Indian reservations. Its population is small (approximately 300), there is housing, an industrial area, a recreation complex and retail area. Space heating of the industrial and administration areas is carried out by a district heating system. This is an ideal situation since heating of remote communities by a district heating system supplied by any alternate energy source would be a necessity. Electricity is supplied by Manitoba Hydro while the houses and Station buildings rely on heating oil and diesel fuel respectively to provide the heating needs.

Utilities

The station operates primarily on electricity supplied by Manitoba Hydro through a 198 KVA substation adjacent to DND property. Because of electrical storms that are prevalent in the area during the summer the diesel generators are on an operational standby basis and cut in and provide power to both sites on an "as required" basis. The power plant contains 3 Orenda diesel 750 KVA turbines with integral Foster Wheeler waste heat boilers - total output is 2.25 MW. If the plant is required one turbine is adequate to handle the maximum Station load of 750kWs. The second turbine is on standby with the third is down for routine maintenance and overhaul.

Primary heating for the industrial area is provided by a district heating system composed of two 200 h.p. Volcano boilers, and two 50 h.p. boilers for the operations area. Steam is supplied to the buildings through 4870 feet of buried steam distribution lines. It consists of insulated steam and condensate pipes in separate metal conduits buried below the frost line. Generally one 200 h.p. boiler (equivalent to 1900 kWs) can provide sufficient steam for all station buildings except on extremely cold days, however this is not a common occurrence. Foster-Wheeler waste heat boilers (3 x 480 h.p.) in the power plant can be fired up, in conjunction with the turbines, to provide sufficient extra capacity (up to 1440 h.p.) during extemely long cold periods, or if the main boilers fail. They were used before the site went to commercial power, in effect a cogeneration system. The Married Quarters are heated by individual oil-fired furnaces.

The water supply is drawn from a deep well located in the residential area providing a potential 346 M gals/day and there is a 200 M gallon reservoir. Water is chlorinated and softened at the water treatment plant before distribution. There are 9500 lineal feet of metal pipe in the MQ area and 9500 feet in the main Station area. Sewage is treated by chlorine and fed to a two-stage sewage lagoon, the primary cell containing 2.5 acres and the secondary cell of 3 acres.

The consumption of the various fuels and electricity over a period of years has been compiled and a summary of the most current data is shown by Table 7. By utilizing this data a calculation of the various

TABLE 7 CANADIAN FORCES STATION GYPSUMVILLE UTILITIES REPORT

NO	ITEM	BASE YEAR	83/84	84/85	REMARKS
1	Tot Bldg Area km^2	23.9	23.9	23.9	
2	Average Population	380	375	384	
3	Degree Days (C')	6018	5784	6721	
4	DD x Area (1 x 3) k	132	138	161	
5	Water, km^3	116	88	113	
6	Sewage, km^3	80	80	87	
7	KWH Base Total, k	8911	8492	8190	
8	KWH Generated, k	1564	151	121	Now commercial power
9	Fuels, Liq Elect, m^3	1900	149	125	
10	Fuel, Liq MQ, m^3	468	330	301	
11	Fuels, Liq Htg Tot m^3	1644	1310	1468	
12	Total Energy (GJ) k	162	86	90	

13 Conversions

1000 Gal = 4.546 m^3
1000 KWH = 3.6 GJ
PMQ Oil = 37.76 GJ per m^3

1 MBTU = 1055 GJ
k = 1000 units
CHP oil = 38.34 GJ per m^3

Source: CFS Gypsumville Quarterly Conservation Report 1985 loads can be undertaken. For this exercise the Station will be divided into two areas, basically as it is now -- the PMQ housing area and the Station proper.

PMQ Housing Area

The determination of the energy requirements for the PMQ area is relatively straightforward. Each PMQ unit (97 in total) is the same size and of the same construction i.e. 1000 sq ft and double-wide trailers , has one oil-fired furnace and is supplied by Manitoba Hydro. Consumption will, of course, vary with the occupant but can be generalized. Total oil consumption, averaged over two years was 315.5 k m^3 or 69,401.67 gallons equating to 715.48 gallons of oil per PMQ. The base year was slightly over 50 % higher than current consumption due in large part to a change in billing procedures. Previously the cost was averaged out with the occupant paying a flat rate and did not reflect true consumption figures. Now the occupant is billed directly; this fact combined with higher prices and the installation of set-back thermostats has over the years dramatically reduced consumption.

Electrical consumption averages 6000 kWh per year for each house therefore the total load is 582,000 kWh per year. This consumption does not show up on the report for the current years. Therefore a 70 kW generating unit would be required to produce this power. The PMQ's could be heated by electricity; on the average each PMQ would require an electric furnace with a total capacity of 20 kWs (other units include unitary, hydronic or wood-electric systems). The peak load will be the coldest day of the year and it will vary downward from there.

Station Area

The Station buildings use on the average 1389 m^3 or 305,543.33 gallons of oil for heating. This heating fuel is used to operate the station heating plant (2-200 H.P. boilers); one boiler is required to generate sufficient heat to supply the buildings, equivalent to about 2 MWs. There has not been an equivalent drop in consumption since the base year as there was no overall incentive to conserve energy. An energy conservation program is now in effect which accounts for the drop in consumption.

It took 125 m^3 fuel or 27,496.7 gallons of oil to generate 121,000 kWh of electricity therefore 4.4 kWh require one gallon of diesel fuel. This total represents the time the power plant is in operation during the summer when the area is prone to electrical storms. This figure will then vary according to the weather. However this amount is included in Ser No. 7; it is only useful to determine the average amount of fuel to generate electricity and can be used a guideline.

For the Station area the average total kWh used per year is 8,341,000 (average of years 83/84 and 84/85). The operational area is included in this total. It will be assumed that this amount equates to 20 % of the total use or 2,085,000 kWh; therefore the load for the Station area itself is 6,256,000 kWh per year. This figure then represents the average Station load based on two years consumption figures. For design purposes, the system chosen will have to generate this amount of electricity. Substituting 8760 hours per year into the equation, the power required is approximately 720 kWs. This represents the peak load at any one time. This equates nicely with the fact that one 750 kW turbine can provide the power for the peak station load.

Site Analysis

The site should be analyzed in its ability to adapt the various energy sources to the existing conditions. Mohammed, in his 1980 thesis "Energy Efficient Housing Design," investigated the ways that energy can be conserved through a rational approach to the design of buildings and towns. His 12 design principles were postulated in order to determine the effects of each for conserving energy. He concluded that all twelve contributed to some energy savings.[79] Many incorporate the concepts of well-insulated double E standard homes of today. Other principles involve the building and its shape, location and orientation on the lot.

Energy savings are important for our discussion since for every extra kilowatt of energy produced incurs an extra cost thereby increasing the overall cost of each system. When the buildings and homes were built in the 60's energy consciousness was not uppermost in people's minds. Nothing much can be done with the buildings' location, orientation and shape on the lot, but a complete energy retrofit can be accomplished to reduce as much as possible energy losses. This in effect reduces the total energy requirements of the structures. A total retrofit was estimated to cost $4,000 per 1100 sq. ft. house (1980 $); [80] this cost would probably approach $8,000 today. An example of how much savings there are with this retrofit is shown when average monthly kW.hr. use for electric heat is compared with that of an 1100 sq. ft. super energy efficient R2000 home i.e. 1800 kW.hr. vs 412 kW.hr. Retrofitting will not gain as much savings, but it would be cost effective to carry out these changes.

Robert W. Walford, in his 1983 thesis titled "Solar Energy for Existing Houses", determined that, even though each system had limiting factors for ultimate potential, thermal upgrading was necessary. [81] In addition Walford confirmed Mohammed's premise that physical characteristics of the site were as important as the system itself. [82]

Nothing can be done with the site itself, only the systems can be matched to existing conditions. As this is a small community, the problem of restrictive solar access is not seen as a limiting factor. Orientation on the lot for the majority of the PMQ's and buildings is quite good i.e. on the preferred east-west axis. PMQ roof areas will be a limiting factor when size of solar collectors is determined; this will not be the case for the buildings. The PMQ's have no basements therefore construction of heat storage areas will be a problem as they will have to be installed underground or attached to the houses. Group storage areas and a collector array will be a necessity ; in fact they are probably more cost effective than individual units. It will be advantageous to do the same for the buildings. In fact the existing heating system for the station is a district heating system. The characteristics are the same: a heat source, in our case a diesel boiler; and, a distribution system using steam or hot water.

The site plan shows that there are plenty of open spaces and treed areas within Department of National Defence boundaries that can be used for the construction and installation of the alternate energy sources. In addition the existing distribution systems can be utilized.

Table 8 details the energy consumption of CFS Gypsumville. This data will be used as a guideline in order to evaluate the different systems and their parameters and costs can therefore be estimated.

Summary

CFS Gypsumville is a self-contained community located 150 road miles north of Winnipeg. It can be compared to small remote settlements that the National Energy Program has said lend themselves to the utilization of alternate energy sources. The energy requirements have been outlined and the next chapter will determine the best alternate energy sources to meet them.

From a general review of the climate conditions reveals that solar radiation and wind data would be suitable. The nearest wind stations are Grand Rapids and Dauphin with a mean wind speed of 19.4 and 17.6 km/hr respectively, within the required threshold.

A district heating system and probably a co-generation system providing both electricity and heating will be used. The station buildings are currently operated on a district heating system which should be expanded to include the PMQ area.

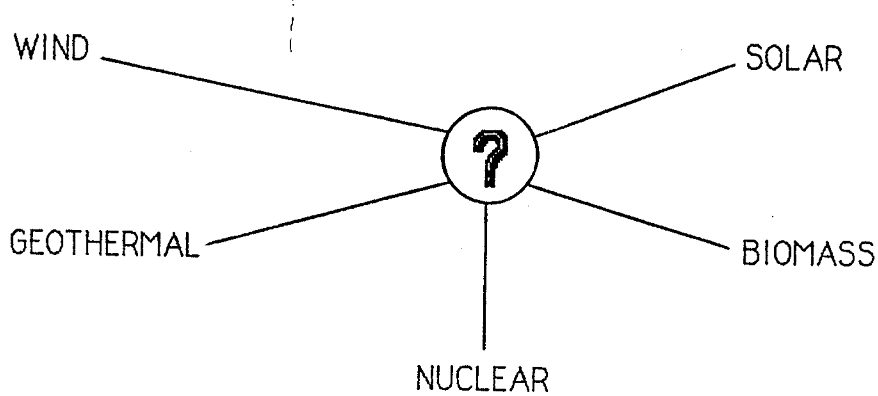
Table 8 ENERGY CONSUMPTION FOR CFS GYPSUMVILLE

Electrical	Kilowatthours	Gigajoules
Station	6,256,000	22,521
PMQ's	582,000	2,095
Heating	m^3 Oil	Gigajoules
Station	1,389 1,373,721 (1)	53,254
PMQ's	315.5 312,029 (1)	11,913

Conversions 1000 kWh = 3.6 GJ $1\ m^3$ = 37.76 GJ (PMQ)
= 38.34 GJ (STATION)
= 989 litres (1)

Source: Data compiled from station records.

Figure 30: FUTURE ENERGY ALTERNATIVES FOR CFS GYPSUMVILLE



AUTONOMOUSLY SERVICED SETTLEMENTS

CHAPTER FOUR

CASE STUDY

ALTERNATE ENERGY SOURCES FOR CFS GYPSUMVILLE

INTRODUCTION

In the previous chapter the various methods for providing alternate sources of energy were outlined. In general the sources discussed all had proven to be suitable methods, except for fusion energy, for replacing non-renewable fuel resources at remote locations. These remote locations were deemed to be those far removed from major hydro, oil and gas distribution systems.

All alternate energy sources were site specific, that is the location of the site-its latitude, longitude, climatic and weather characteristics - determined the ultimate viability of each system. For example, Wind Energy Conversion Systems depended upon the average velocity of the wind at a particular site and solar energy systems depended upon the amount of sunshine received at that site. One case, nuclear fission energy in the form of the SLOWPOKE reactor, did not depend upon site location except for the problem of public acceptance. But, ultimately the cost of the energy provided would be the overriding factor (as it would be for all these systems).

This chapter will examine each alternate energy source and describe the various systems envisaged for our test site. Solar energy systems will be outlined first as they appear to be the most viable at this point. Wind, nuclear energy, biomass and finally geothermal energy will detailed. To conclude, the best system or a mixture of energy systems will be recommended as the "ideal" or most promising system(s).

The previous chapter described the site characteristics and power requirements (both electrical and heat) of CFS Gypsumville. This information will be used to tailor the energy systems to the energy requirements of the site.

As we have stated, Gypsumville is a suitable location for most of the energy systems. Just to summarize; wind characteristics are considered sufficient, it still is at a latitude where solar energy can be usefully employed even during the winter months when solar energy is at its minimum (the one drawback is that more energy is required for heating during this minimum solar energy period). It is in the prairie central platform region where geothermal energy is probably available, however only detailed investigation will determine the system's viability in the long term. This has not been done: as a result only a probable configuration will be described.

Biomass is another intangible that is difficult to assess without a detailed analysis. Energy plantations in the form of short rotation tree farming, the municipal waste and the sewage system are probably the best methods of utilizing this resource. The SLOWPOKE reactor appears to be the system with the most advantages. The technology has advanced to a point where it has been shown that it is a viable alternative.

Each of the alternate energy systems will now be described as to their potential for providing the heating and electrical needs of the station.

SOLAR ENERGY

Chapter two described three basic methods of utilizing solar energy - active, passive and photovoltaic systems. Passive systems are used for space heating, primarily single family residences. Three methods are usually used; direct gain, indirect gain and isolated gain. All three could be used to provide additional heat to the residences and office buildings. Using them would be difficult and expensive because the existing architecure would have to be modified. The houses are double wide trailers with no basements that make renovations difficult and expensive.

Active systems use mechanical means-pumps and motors-to regulate and transfer heat to the structure. Storage systems, pebble-beds or water tanks, assure that heat is available throughout the day and night. In this case each house and building could be outfitted with its own system or a district heating scheme could be used. District heating would entail the construction of a large collector and storage unit to provide heating for a group of buildings and/or houses. Generally this would be more efficient and cost effective due to economies of scale.

Photovoltaics use the sun's energy to generate electricity by activating a silicon solar cell. Two methods are available: fixed flat-plate collectors and solar concentrators. Generally solar concentrators (not for PV generation) are best at lower latitudes and when used for large scale power applications. In our case the fixed flat-plate collector will be utilized.

Active Energy Systems

Active systems use mechanical means to distribute heat throughout the building. There are two heat transfer fluids that can be used each with their own advantages and disadvantages. Air is one medium and water or a water/glycol mixture is the other. Both mediums work on the same principles requiring collectors, pumps/blowers and storage systems.

Either system could be used; an air system for the MQ's would be appropriate since the existing heating ducts could be used. The houses are about 1000 sq ft and would provide close to 500 sq ft of roof area to install solar collectors. Unfortunately collectors of this size would only provide up to 60 % of the total peak load (this assumes that the house is well-insulated i.e. to Double E standard; they are not, so the percentage of peak demand would be less). In addition, the existing roof probably would not support the installation of solar collectors. Compounding the problem is the fact that there are no basements which makes it difficult to install any form of storage medium. At least three days storage capacity is required; however if 100 % of the heating load is to be provided, seasonal storage is required.

Rock bed storage units are normally used with air systems. However this storage unit would be 2 to 3 times the size when compared to liquid based systems. As the MQ's have no basements it would be more efficient to construct a central storage unit rather than trying to put in individual basements and storage units or alternately storage units dug in the backyard. The advantage is that the greater the number of houses tied into one unit the less the overall cost and size of the storage unit due to economies of scale. If flat-plate collectors are replaced by evacuated tube collectors the size of the storage unit would decrease due to the improved efficiencies. It has been suggested that with the addition of heat pumps further reductions may be possible. However the fact that heat pumps require electricity to operate may mitigate against their use.

As well, air based systems would work for apartment blocks and office buildings but not for many single detached houses due to the heat losses in trying to distribute heated air over long distances. In this case each MQ would have its own rock bed storage unit under the backyard and solar collectors installed on the backyard. Normal flat-plate collectors would require a storage volume of more than twice the volume of the house to provide 100% of the space heating load. By switching to evacuated tube collectors the volume of storage would be reduced by one half due to increased efficiencies during winter. Other storage mediums like phase change materials may be advantageous but they have not been developed enough to confirm their suitability.

Liquid based systems have basically the same parameters as air based ones although the volume of the storage unit is typically one third less. The same problem does arise due to the fact that there are no basements. Therefore a central storage unit would be required. The problem with distributing the hot water would not be as restrictive as with heated air.

Sweden has had experience with central solar heating systems (small-scale district heating) for office buildings, terraced houses and detached houses. [83] The first two use air as the heat distribution medium and the latter use water. The majority were originally designed to provide 100% of the heating loads. These four projects are located in cities situated in the southern part of Sweden approximately between the 56th and 60th parallel. Figure 31, page 137 shows their location. Southern Sweden is generally at the same latitude as Thompson and Lynn Lake, Manitoba so these installations could be adapted to meet our requirements. Table 9 illustrates the system parameters.

Figure 31: District Heating in Sweden.

Source: Energy Conservation Through District Heating Report of Study Trip 1975.

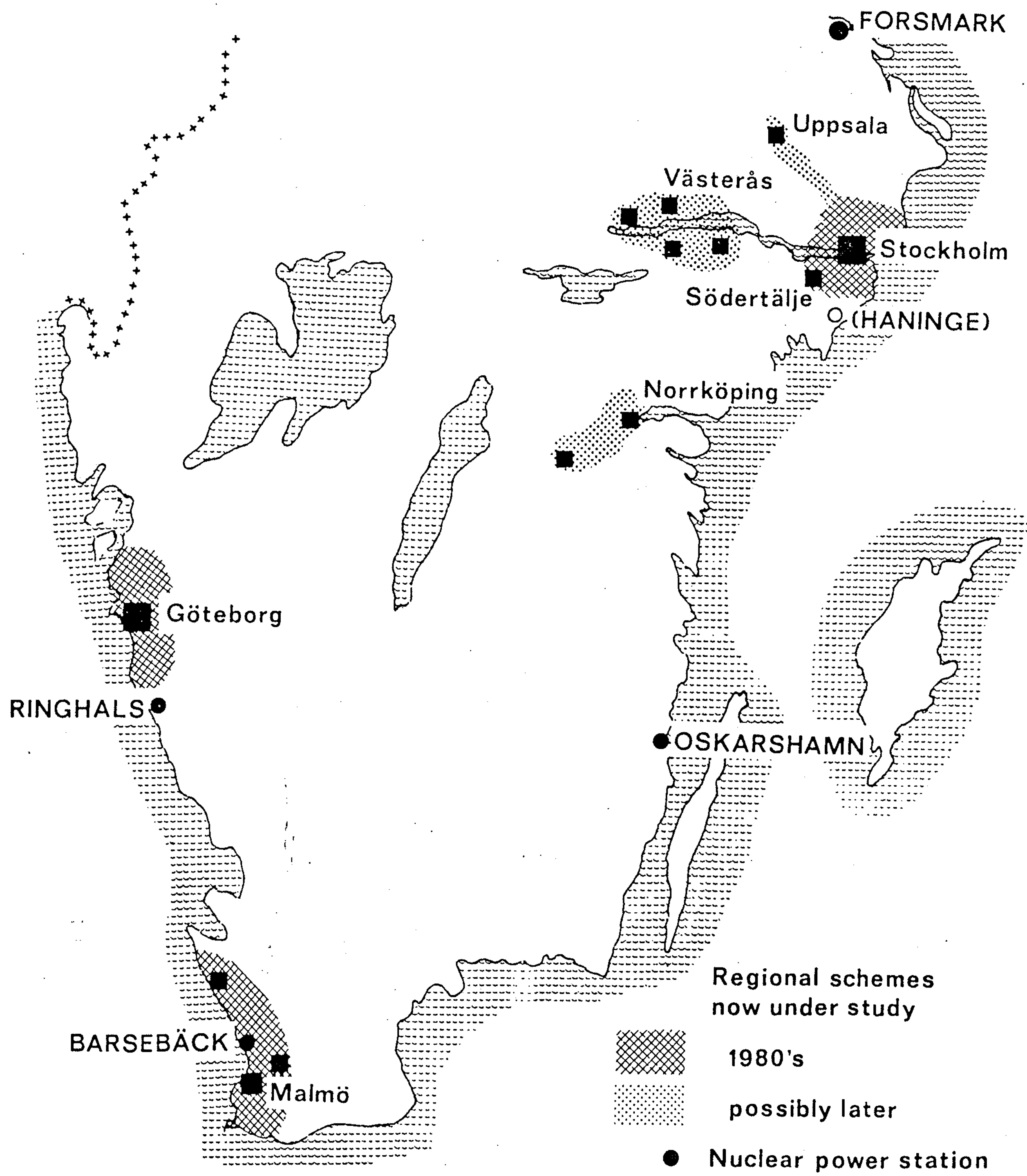


Table 9: Technical comparison (as initially designed) of Solar heating systems in Sweden.

Project	Studsvik	Lambohov	Ingelstad	Lyckebo
Volume of heat store m^3	640	10,000	5,000	100,000
Storage capacity MWh/year	19	750*	300	5,500
Store temperature 'C	70/30	70/5	95/40	90/40
Type of store	Ground Excavation	Excavated Cylindrical tank	Above-Ground concrete tank	Rock cavern annular form
Dimensions m	Depth 6 Diameter (surface) 16 Diameter (bottom) 6	Depth 16 Diameter 32	Depth 8 Diameter 28	Depth 30 Diameter (outside) 75 Diameter (inside) 35
Heat supplied to	Office Building, 500 m^2	55 terraced houses	55 Detached houses	350 Detached houses, 200 apartments
Annual coverage %	100	100*	50	100**
Heat Distribution medium	Air	Air	Water	Water
Solar Collectors	Concentrating on the tank cover, Solar Tracking	Flat, on building roofs	Parabolic concentrating on ground Solar Tracking	Flat Plate Ground mounted
Surface m^2	120	2900	1300	4300

* Including heat pumps ** 85 % simulated by an electric boiler

Source: Experience from three full scale solar heating plants, E. Gabrielson, Invited Paper, from Proceedings of Energex '84 (Pergamon Press, Toronto, 1984), p. 564.

The Station buildings would be under the same constraints as the MQ's. Either air or liquid based systems could be used, but each building would require its own unit (there are no basements). The roof areas are large enough to mount solar collectors and storage units could be added as additions to the buildings. The better option is to have a central collection and storage system, in effect a district heating system.

Costs for these systems must now be estimated. A recent installation of an active solar system at the MacLaren Pulp & Paper Mill in Masson, Quebec can provide a benchmark from which to work. The system comprised 48 modules, each one 16 by 32 feet, or 2,260 square meters covering an acre of land costing $750,000. It is tied in with their existing steam plant through a closed loop, glycol system. Total peak output is, in electrical terms 1.5 MWs (5 GJ or 5,000,000 Btu's per hour) giving a total output of 8145 gigajoules a year (3600 MJ per sq m of module).

Our requirement for heat has been stated as a peak load of 2.75 MWs or 9400 GJ; therefore calculating that a peak of 2.2 GJ is produced per sq m the total area required is 4,270 sq m at a cost of approximately $1.5 million. These modules would cover an area of 2 acres. In addition a means of energy storage would be required; in this case either a water tank or rock cavern. Seasonal storage is preferred due to the fact that the largest load is in December and January when solar insolation is at its lowest. It is estimated that the storage system would cost as much as the solar collectors. The larger the system the less total storage volume is required. As an example the volume for 100 homes would not be 100 times the value for a single home but 70 times the volume or 10 per cent of the total heating load rather than 25 per cent. The only drawback is the fact that electricity would have to be produced by some other means i.e. wind, biomass or photovoltaics.

Passive Energy Systems

Passive systems do not rely on mechanical means for the capture of solar energy, nor for its storage and distribution. Most houses and buildings that have south facing windows have a small portion of their heating load provided by the sun without any additional means being added. There are generally two passive energy systems available that will work well inManitoba. These are direct gain, in reality south facing windows; and, indirect gain, glazing combined with a thermal mass in the form of a concrete block wall (Trombe wall) or a water wall. For both systems night insulation in the form of shutters, drapes and/or blinds a necessity. Air infiltration must be kept to a minimum to reduce heat losses.

These systems do not provide for the total heating load but replace from 5 to 15 per cent of the existing source. The maximum value would occur with houses that are specifically designed and built to efficiently use passive heating. In the case of the MQ's the minimum amount would be provided due to the condition of the houses. About half do not face south at all, while others do to some extent. Insulation values are low, probably R7 with air infiltration prevalent. Adding casement triple pane windows and insulation providing a maximum R25 would be the most cost-effective. Total cost per MQ for these alterations would cost at least $8,000. In any event another system would be required to provide for water heating at an additional cost of $2,000.

The Station buildings are also poor candidates for passive heating systems due to the same reasons as MQ's. Passive heating would not be recommended except to utilize what can be provided without renovations or modifications to existing structures.

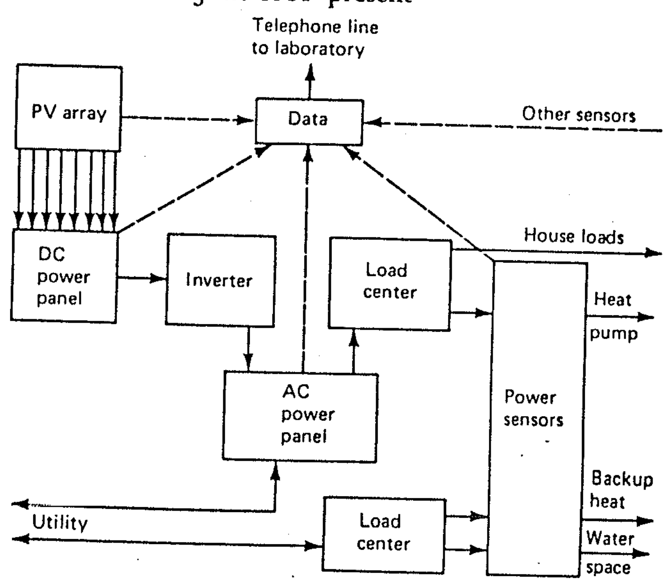
Photovoltaics

Photovoltaics use solar energy to generate electricity. Figures 32 and 33 illustrate typical systems used for single family residential dwellings and larger applications - in this case a remote national park Ranger station. The figures show the various components of a photovoltaic system: array of fixed-flat plate solar collectors, control unit, inverter (DC to AC power), storage unit (battery bank) and system loads. These peripheral components are referred to as balance-of-system (BOS) components.

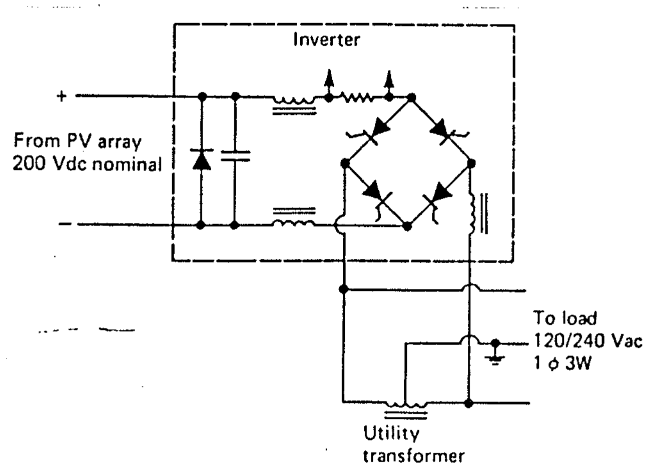
Carlisle House System Description.

Figure 32

APPLICATION:	All solar-electric residential house
LOCATION:	Carlisle, Massachusetts
PV ARRAY OUTPUT:	7.3 kW at 46°C; 190 V × 4.25 A
PV ARRAY CONFIGURATION	
ELECTRICAL:	9 modules in series by 14 in parallel
PHYSICAL:	Residential roof standoff mount: 7 modules high by 18 modules wide
PV ARRAY AREA:	99 m^2
ENERGY STORAGE:	Utility grid
BACKUP POWER:	Utility; passive and active solar heating
POWER CONDITIONING:	8-kVA line-commutating inverter with fixed voltage input
LOAD:	38,500 Btu/h heat pump (at 8.5°C) Backup resistive heating Electric cooking, clothes washing and drying, hot water (as backup to 10-m^2 active solar hot water collectors), and normal residential loads
OPERATION TIME:	June 1981–present



(a)



(b)

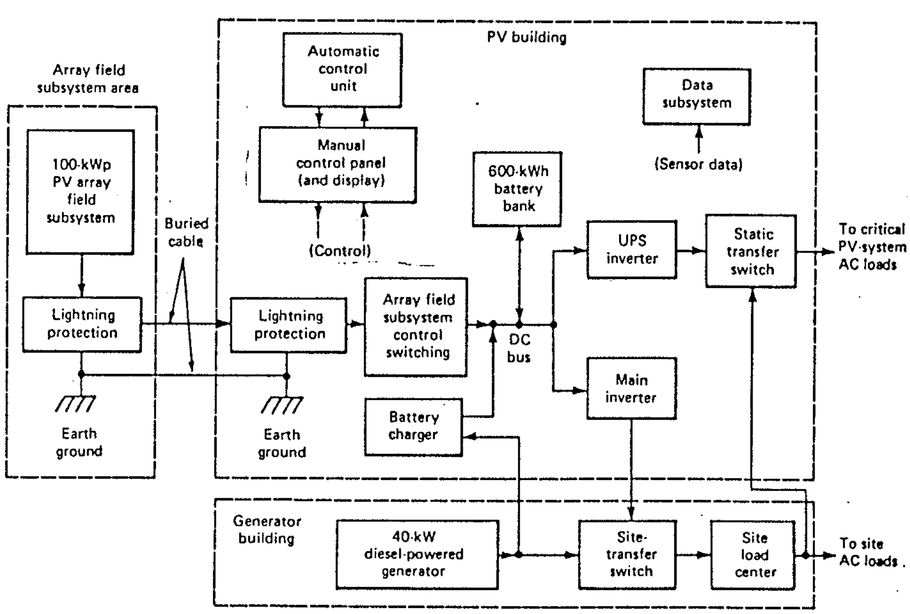
Carlisle House: (*a*) PV-system circuit diagram and (*b*) utility-inverter connection. (M.I.T. Lincoln Laboratory.)

Figure 33: Remote ranger station PV-system circuit diagram

Source: Photovoltaic Energy Systems, Buresch, E., 1983. (Fig 32 & 33)

Remote Ranger Station System Description.

APPLICATION:	Solar-powered remote national park ranger station and residential settlement
LOCATION:	Natural Bridges National Monument, Utah
PV ARRAY OUTPUT:	100 kWp at 20°C; 220 V × 450 A (approx.)
PV ARRAY CONFIGURATION:	
ELECTRICAL:	20 branches: 5 modules in parallel by 7 in series 21 branches: 48 modules in series by 2 in parallel 14 branches: 15 modules in series by 4 in parallel 1 hybrid branch
PHYSICAL:	Rack mount: 96.7 m × 2.2 m panels in 20 rows with 4-8 panels each
PV ARRAY AREA:	Array: 1450 m^2 Land: $1^1/_3$ acre
ENERGY STORAGE:	Lead-acid battery, 750 kWh capacity 213 Vdc nominal discharge voltage
BACKUP POWER:	Diesel generator
POWER CONDITIONING:	5-kVa dc-to-ac inverter for power system control; 50 kVa inverter for site power; array-shedding battery protection circuitry
LOAD:	5 residential houses and 1 visitor center, machine shop and maintenance building, water pumping, trash compacting, external lighting
OPERATION TIME:	May 1980 to present



The Ranger station and settlement utilize 1450 m^2 or 1 and 1/3 acres of solar cell arrays to meet its power requirement of 100 kW(p). In general this equates to 14.5 m^2 for each kW(p) generated. The Carisle House residential PV system has an output of 7.3 kW provided by 99 m^2 of arrays or 13.56 m^2 for each kW(p) generated.

Generally an average house requires electricity totalling 8000 kilowatt-hours annually (does not include electric heat). The use of photovoltaics to provide this power translates into an added cost of more than $30,000 to the price of a new house. In comparison, electricity from Manitoba Hydro costs almost one-tenth that of PV electricity. A typical photovoltaic array for a 1200 sq. ft. house would consist of some 70 two-by-four modules. Each module would contain 72 semi-crystalline silicon cells rated at 58 W of peak power under full sunshine for a total output of 4.0 kW. Each cell would average 100 cm^2, operate at an average efficiency of 15 per cent and produce 1/2 watt (peak). For an all electric house, the cost of the PV system is $150K. [84] This dollar value would depend upon climate, topography, air tightness of the house, etc.

For the industrial and administration areas of the station, a total peak power of approximately 750 kW is required. By using the parameter that 1 kW(p) requires 14.5 m^2, 10,875 m^2 or 2.7 acres of solar cells would be required to meet the peak electrical load. The heating load is estimated at 2 MWs; then 2000 kWs require an area of

29,000 m^2 or 7.14 acres of land. Therefore a total area for the Station area is approximately 10 acres. The collectors would be south-facing and tilted to 53' for maximum output. The arrays would then be tied into the (BOS) components and power distributed through the existing transmission lines.

For the Married Quarters, each MQ could have its own individual system as per Figure 33, or combined into one system per block of eight to ten houses or one central large system for the entire site as detailed by Figure 32. Economies of scale indicate that the latter option is preferred. The PMQ area has been estimated to require 750 kW for electricity and 750 kW for heating; then 1500kWs would require an area of 21,750 m^2 or 5.5 acres. Thus the total area required to contain the solar cell arrays would be approximately 16 acres.

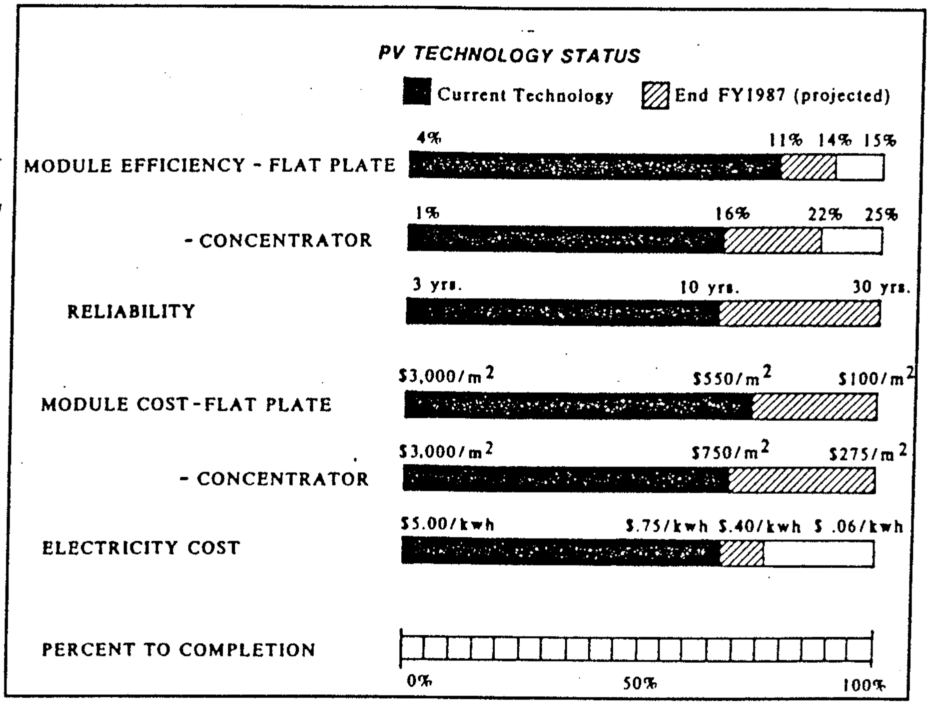
Costs now have to be factored into the equation. Recent installations of PV modules, albeit in small increments 10 kW for $8.50 per peak watt (Installation at Big Trout Lake during the winter of 1985/86). Our requirement is 4.25 MWs at a cost of $36.1 million. Economies of scale would indictate that the per unit cost would less by possibly 20 %. A storage facility has not been included in the cost. The most common form of storage is lead-acid batteries. Without doing detailed calculations it is difficult to determine the required amount of batteries. There have been no large scale PV installations in Canada that can be used as comparisons.

As the peak loads for each MQ and building would not occur at the same time, the total power required might be less. This could be offset due to the fact that the available output of the cells is reduced by about one-third in extreme temperatures. In fact in a small community the electricity use might well be better controlled. This is one of the avenues open to reduce the power factor, ideally helping to decrease the total cost of electricity. An alternate to solar cells for heat is the use of active or passive solar heating systems. Or a combination of systems could be used; diesel generators and/or wind turbines. Some of these systems are more aptly suited to heating applications than are photovoltaics.

The disadvantages of the system includes the one main factor that militates against the use of solar energy - it is a variable resource. The problem with PV cells is that the power output varies throughout the day - from 0 before first light to a maximum at solar noon and back down to a minimum at last light - typically in the form of a bell curve. In addition the time of year and climatic conditions - cloud, rain and snow - cause the output to vary. Generally the power output varies by a factor of about 3 to 1 from summer to winter. The low sun angle, high wind chills and reduced efficiencies due to conductive and radiative losses account for the power drop.

There are two ways to compensate for this effect: one is to increase the area of the collector; and, the other is to increase the storage capacity of the system from several days to several weeks.

Figure 34: PV Technology Status



LONG-TERM GOALS (LATE 1990's)

	FLAT PLATE SYSTEMS	CONCENTRATOR SYSTEMS
MODULE EFFICIENCY	13%-17%	23%-29%
MODULE COST	$40-$75/m^2	$90-$160/m^2
BALANCE-OF-SYSTEM TECHNOLOGY		
-- AREA-RELATED	$50/m^2	$100/m^2
-- POWER-RELATED	$150/kW	$150/kW
SYSTEM LIFE-EXPECTANCY	30 YEARS	30 YEARS

↓

6¢/kWh

REQUIRED IMPROVEMENTS

FLAT PLATE SYSTEMS	CONCENTRATOR SYSTEMS
• FACTOR OF 1.2-1.5	• FACTOR OF 1.5-2.0
• 5X REDUCTION IN COST	• 5X REDUCTION IN COST
• FACTOR OF 2	• FACTOR OF 2
• 10X REDUCTION IN COST	• 12X REDUCTION IN COST
• FACTOR OF 3	• FACTOR OF 6

Source: SOL Vol. 54 July-August 1986, pg 2.

Each one however also increases the cost of generating elecricity. These factors combine to make photovoltaic energy an inferior cost-effective resource to replace fossil fuels. If money were no object, these systems would be used. And when there is an order of magnitude drop i.e. from $13 per Wp to $3 per Wp in the costs of these cells, photovoltaics will see more use. Figure 34 summarizes the current PV technology status, long term goals and required improvements in performance required before PV's see widespread use.

Nuclear Energy

Chapter two described two methods for producing energy-both heat and electricity - from the primary elements: nuclear fission and nuclear fusion. Fusion will not be discussed further as the technology has not advanced to a state where it is feasible and only then on a very large scale - on the order of 1,000 MW's. Fission in the form of small scale production by the SLOWPOKE reactor, was determined to be the best method of utilizing nuclear energy.

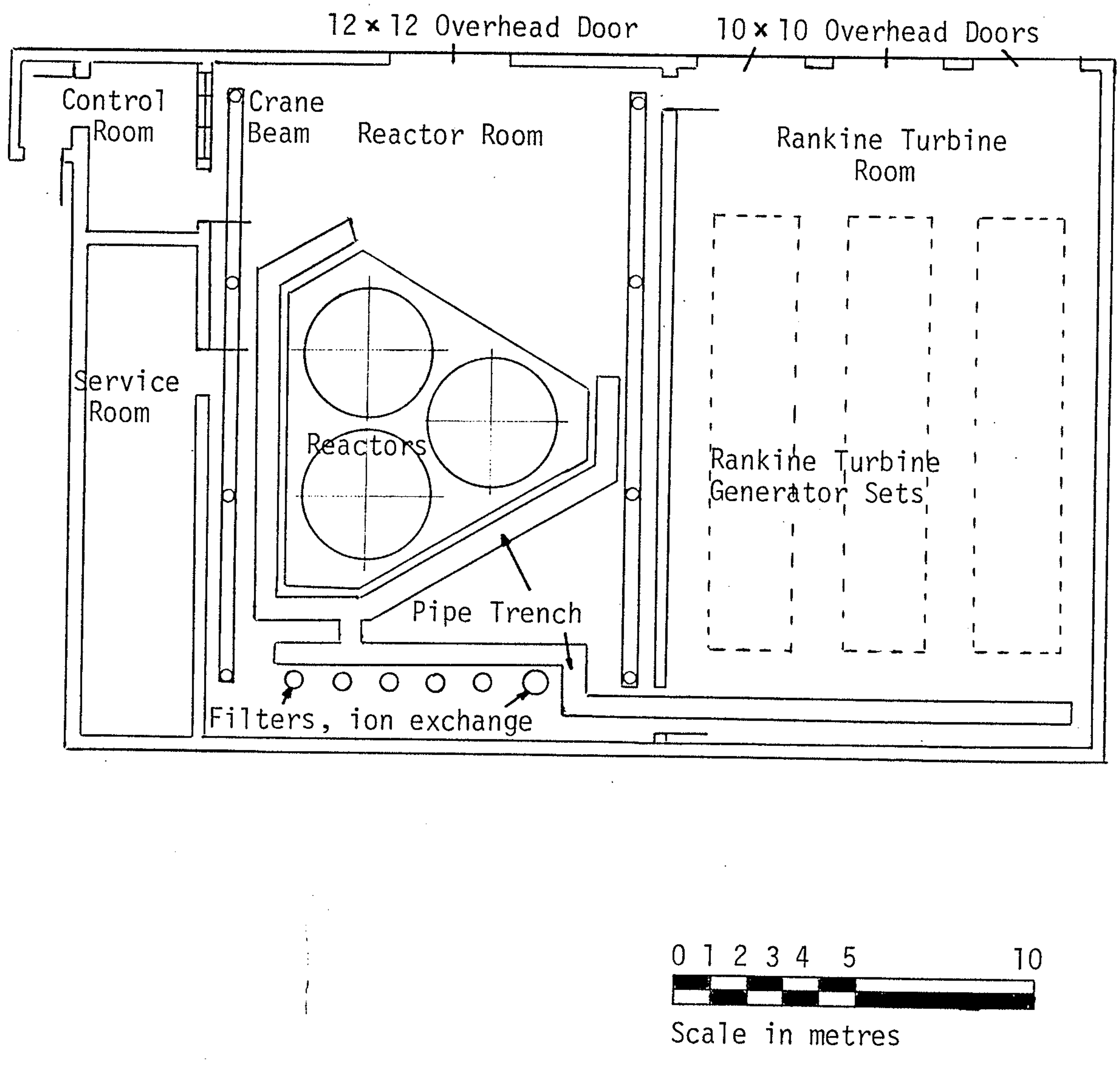
The SLOWPOKE reactor has been developed by AECL to provide energy at the 2 MW(th) level - suitable for most small-scale applications. The primary application is for heat but it can also be utilized for the production of electricity. Typically the relationship between heat and electrical output is generally given by the relationship: 1 MW (th) is equivalent to 0.33 MW (elec). Generally there are three methods to produce electricity, one is with the use of a Rankine cycle turbine, the second is a heat pump combined with a steam turbine and the third is by using a thermo-electric converter. None of these methods have been developed sufficiently to identify the best one, however AECL is pursuing the Rankine cycle method. With this method efficiencies are somewhat lower than the one-third relationship therefore 2 MW(th) may only produce 250 kW(e).

In the same chapter the design and characteristics of the reactor were identified. It was stated that the reactor is composed of several components: a water filled concrete enclosure, reactor fuel assembly, heat exchangers; along with a control building and energy distribution system. Gypsumville is in a good position because the present steam distribution system can be used with the reactor. This is the case for the industrial, administration and recreational zones. However as the houses in the PMQ area are heated by individual oil-fired furnaces a new distribution line would have to be installed. For the electricity mode the existing overhead power lines and substation would be utlilized.

Installation

It has been determined that the peak building heating load is in the order of 2 MWs i.e. one 200 HP boiler can meet this need. This peak load would only occur during the coldest month of the year. One reactor would be able to provide heat for the station buildings.

Figure 35: SLOWPOKE Reactor Layout



Source: Waldrop, W.L. & Associates, April 1983.

The reactor would be installed below ground in the bedrock, the hole would be 12.5 m deep and 6.5 m wide. The reactor internals would be surrounded by a 1 m thick reinforced concrete container. Inside this would be a stainless steel container filled with light water and the reactor at the bottom of the pool. [85] A control building approximately 12 m by 16 m complete with overhead crane is placed on top of the concrete container. Figure 35 details the structure.

Once the reactor started up the water at the bottom of the pool would be heated and rise due to natural convection. Plate heat exchangers in the pool would transfer heat to a secondary circuit isolated from the pool water. Water in this circuit would carry the heat to a third tube-type heat exchanger filled with a glycol/water mixture for circulating through out the buildings. This third circuit is also isolated, this time from the second circuit. The pool water would be continuously passed through filters and ion exchange columns and then back into the pool. This would be accomplished in a closed loop to ensure no contaminants or radioactivity escaped. The heat distribution lines would be run through the existing steam pits and corridors. It would be a three loop, double pipe, direct return system, with buildings connected to the loops in parallel. Each building would have an in-line type circulating pump to pass the water through the heating radiators. The cooled water then returns to the reactor to begin the process again.

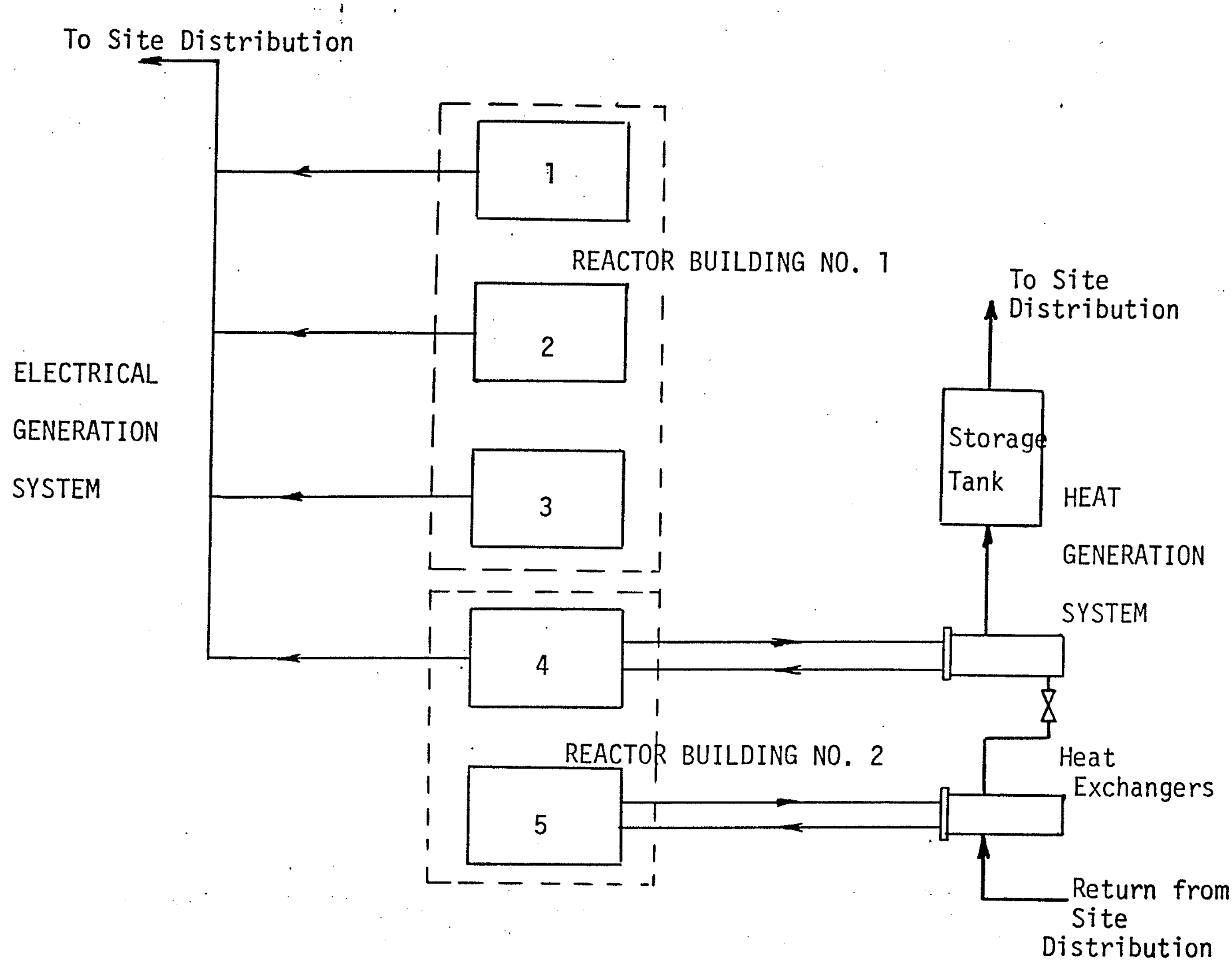


Figure 36: SLOWPOKE Reactors for Heat and Electrical Generation System Block Diagram

Source: Waldrop, W.L. & Associates, April 1983.

This accounts for the Station buildings, but the MQ's have to be included. This would be comparable to the district heating schemes that are so prevalent in the Scandanavian countries. The distribution system would be the same as for the buildings but piping would have to be run to each MQ and hot water radiators installed in each. This work would not be too extensive since the MQ's are located in a small compact area. Figure 36 illustrates the proposed distribution system.

Heat would be required for 7 months but not throughout the year. Loads would increase to a maximum probably in January and down to a minimum, typically mirroring the shape of a bell curve. The reactor would commence operation at some predetermined load level and then continue for 7 months until shut down. Heating lines should not be run too far to reduce the heat losses i.e. no more than 25 kilometers.

Generation of electricity would be similar in operation but with the addition of a Rankine cycle turbine instead of the heat exchangers. It was stated previously that with the Rankine cycle the reactor output drops to 250 kW(e). The peak station building load has been set at 750 kW; adding the MQ load of 200 kW (including electrical water tank) gives a total load of 950 kWs. From this data 4 - 2 MW Slowpoke reactors would be required. Installation would be the same as for heating except that 4 reactors would be in one location and in the same concrete enclosure. This could be revised to have three in one enclosure and two in the other. This latter method would reduce the overall cost of the system by the fact that they would be in two enclosures not five.

The output of the reactors would be fed to the Rankine turbine generation sets and the resultant electricity would be distributed via the existing power distribution lines. It would be advanageous to have one of the other reactors fitted up with heat exchangers to act as a back-up to the primary heat reactor.

The above discussion assumes that the Rankine cycle is the best system to generate electricity from the reactor. It assumes that this system would be 10 % efficient in using Rankine cycle with a 2 MW(th) Slowpoke reactor. If the reactor could be up-scaled to 10 MW's, one could provide both the heat and electrical requirements using co-generation. Once a 2 MW(th) reactor has been constructed and tested, positive answers to the system's feasibility can be determined. The above data has been taken from a technical and economic feasibility study done for DND by W.L. Wardrop & Associates in 1983.

In fact the Atomic Energy Control Board has given its approval to Whiteshell Nuclear Research Establishment to commence operation of their 2 MW Slowpoke reactor. Estimates indicate that the reactor can provide heat to communities of up to 2000 inhabitants. This confirms our calculations that one 2 MW reactor could provide the heating needs of CFS Gypsumville.

An update of this study (March 1986) has incorporated the use of one 10 MW(th) reactor for the total heating and electrical needs of the community. Again the Organic Rankine Engine (ORE) is used with the reactor for the production of electricity. Of the approximate 8 MW heat availabe, 850 kW of electrical power would be produced. Total cost of this reactor has been estimated to be $8 million.[86] In essence Figure 36 would be revised to include one reactor rather than five.

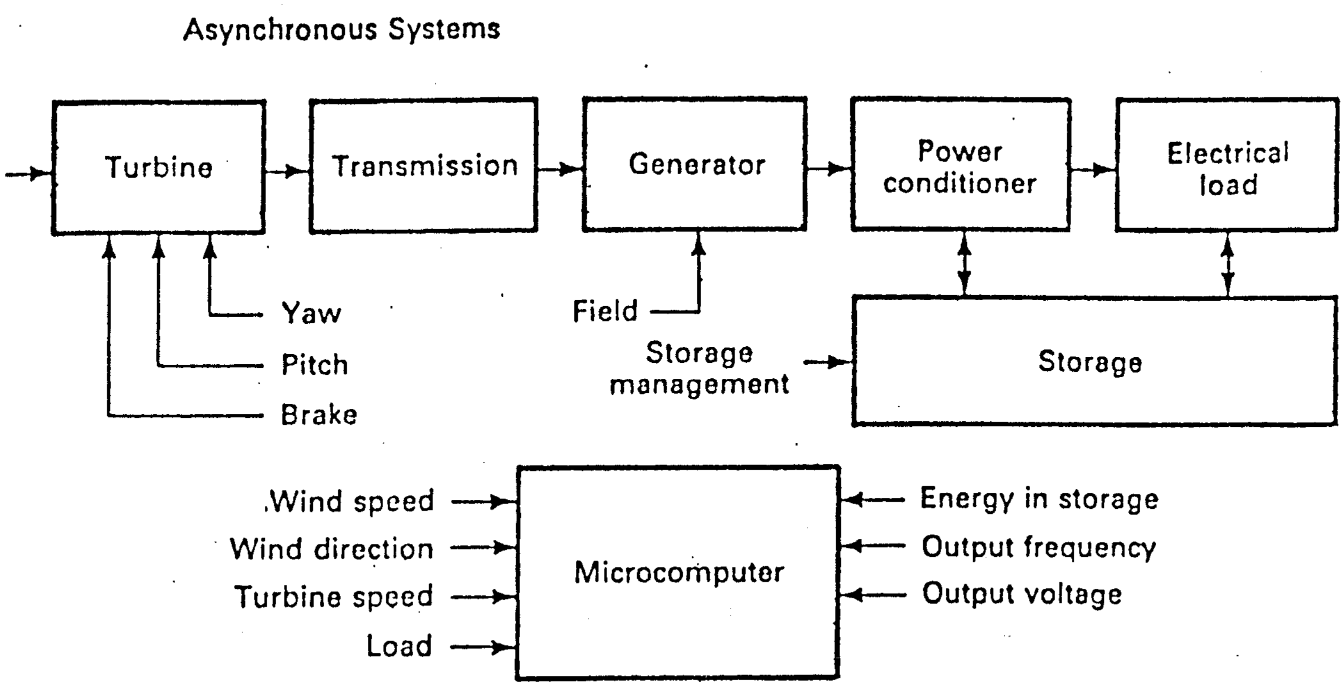
Wind Energy

Chapter two discussed the methods for extracting energy from the wind. Two types of Wind Energy Conversion Systems (WECS) were outlined - vertical axis wind turbines (VAWT) and horizontal axis wind turbine (HAWT). VAWT, in the form of the Darrieus windgenerator, has been developed in Canada, whereas HAWT - either two or three bladed propellers-has been developed by the United States and most other countries. Each system has its advantages and disadvantages over the other. Many more HAWT machines have been built and installed, generally in wind farms in California than have VAWT machines.

In Canada many 50 kW Darrieus windgenerators have been installed and work well, along with a 230 kW machine in the Magdalen Islands, P.Q.[87] The larger machine demonstrated that increasing the size presented no major difficulties and that it worked

Figure 37: Block Diagram of asynchronous electrical system.

Source: Commercial Aspects of Wind Power, Vosburgh, Paul, N. 1983.



according to design specifications. Therefore depending upon the power required, Darrieus wind turbines can be used in our discussion. The final and most important requirement is suitable wind characteristics of the site. Generally at a theoretical rated peak output of 230 kW the average usuable power output would be on the order of 30 per cent or 70 kW.

The use of wind power for electrical power generation however is complicated by several fundamental facts: [88]

1. peak winds rarely coincide with peak energy consumption periods;
2. the storage of wind-harvested energy in batteries, and later withdrawal involves a storage and expenditure loss of initially harvested energy;
3. the only one-way revolving electric generator-coupled windmills inherently produce direct current (DC); and,
4. the electricity generating industry produces and distributes alternating current (AC).

In the United States there are many manufacturers of two and three bladed wind generators rated from 1 kW to 500 kW and several into the megawatt range. Therefore there are many units available for most any application. Usually these machines are integrated into wind farms containing 10 to 50 machines thus increasing the total power output. Generally the larger the "farm" the less costly is the production of electricity i.e. economies of scale work well. Figure 37 illustrates the components of a typical system.

This then is the proposal. Instead of havng one small machine for each building and house on the site, a wind farm would be established. Hard data about the windwould be required first. The average power required for each house is on the order of 1.5 kW (0.75kW for heating and 0.75 kW for electricity). For 100 homes the requirement is 150 kW. As the machines use theoretical power output to identify the machine type, 150 kW translates into 500 kW (assuming 30 % efficiency). For the Darrieus machines, 10-50 kW, 5-100 kW, 2-250 kW wind, or 1-500 kW generators would be required. The same numbers would generally be applicable to the two or three bladed HAWT's.

The same method can be used to determine the requirements for the main building area. Generally one 750 kW turbine can meet the peak load. Using the 30% wind turbine efficiency figure this becomes 2500 kW or 2.5 MW. This translates into 25-100 kW machines, 10-250 kW units or 5 - 500 kW machines. A Darrieus machine rated at 500 kWs would have a rotor approximately 80 feet in diameter. For more than one machine in a typical wind farm, spacing is on the order of 6 diameters. This equates to an area of 600 feet by 600 feet or 8 acres of land. By adding the 2 machines for the MQ area the total land area required increases to 1200 feet by 600 feet or 16.5 acres.

This however does not include heat for the station buildings. It has been estimated that the peak load is on the order of 2 MW. This occurs only during the coldest days of the year. An average load of 75 % or 1.5 MW is assumed. The rated wind power would then be 5 MW requiring 10 - 500 KW machines. This translates into an area of over 38 acres. Therefore a total wind farm area of approximately 54 acres would be required for the wind machines. Each 500 kW unit (DAF Indal) costs $650,000; [89] 17 wind machines would cost $11 Million (1984 $). This is based upon the cost of one machine, 17 would reduce the cost by possibly 15 - 20 % ($2 million).

Today's (1986 $) cost averages $1,000 per kW installed; 8.5 MWs would cost $8.5 million.

In addition to the wind turbines there is the equipment to convert the wind energy to electricity. By referring to Figure 37 the other components include the system control electronics in the form of a microcomputer, the transmission system and a storage facility. The transmission system used is the existing station electrical power lines. The storage system is difficult to predict however a central store consisting of a large lead-acid battery storage bank or thermal storage supplying groups of houses and buildings or one large system serving the complete site is preferable. A diesel unit could be tied in with the wind machines to provide back-up power; this is the system that Ontario Hydro is designing.

GEOTHERMAL ENERGY

Chapter two described three types of geothermal energy that were available for use as alternate forms of energy: hydrothermal deposits; hot igneous systems; and, magma systems. Magma systems were not considered viable due to the lack of technological expertise and experience necessary to make this form of energy economically recoverable. Two other forms are available but use depends upon the type of deposits that are available in any particular area of the world. Energy end-use: space and process heating; and, electricity thus depend upon these deposits.

Manitoba is in the central platform area of the Prairies. Low grade energy, in the form of hot water below 80°C, has been identified as a possibility for this area. Detailed research would have to confirm the exact extent of the deposits below CFS Gypsumville. Nevertheless it is possible to design a hypothetical system for conversion of this low grade geothermal energy to space heating. Generation of electricity is not possible in this scenario as the temperatures are not high enough.

Basically two deep wells would be dug down to the hot water deposits, generally 3000 metres deep. One well would bring the hot water to the surface where it can be distributed to the buildings. The other would re-introduce the return cooler water back into the reservoir where it would be reheated and the process continued.

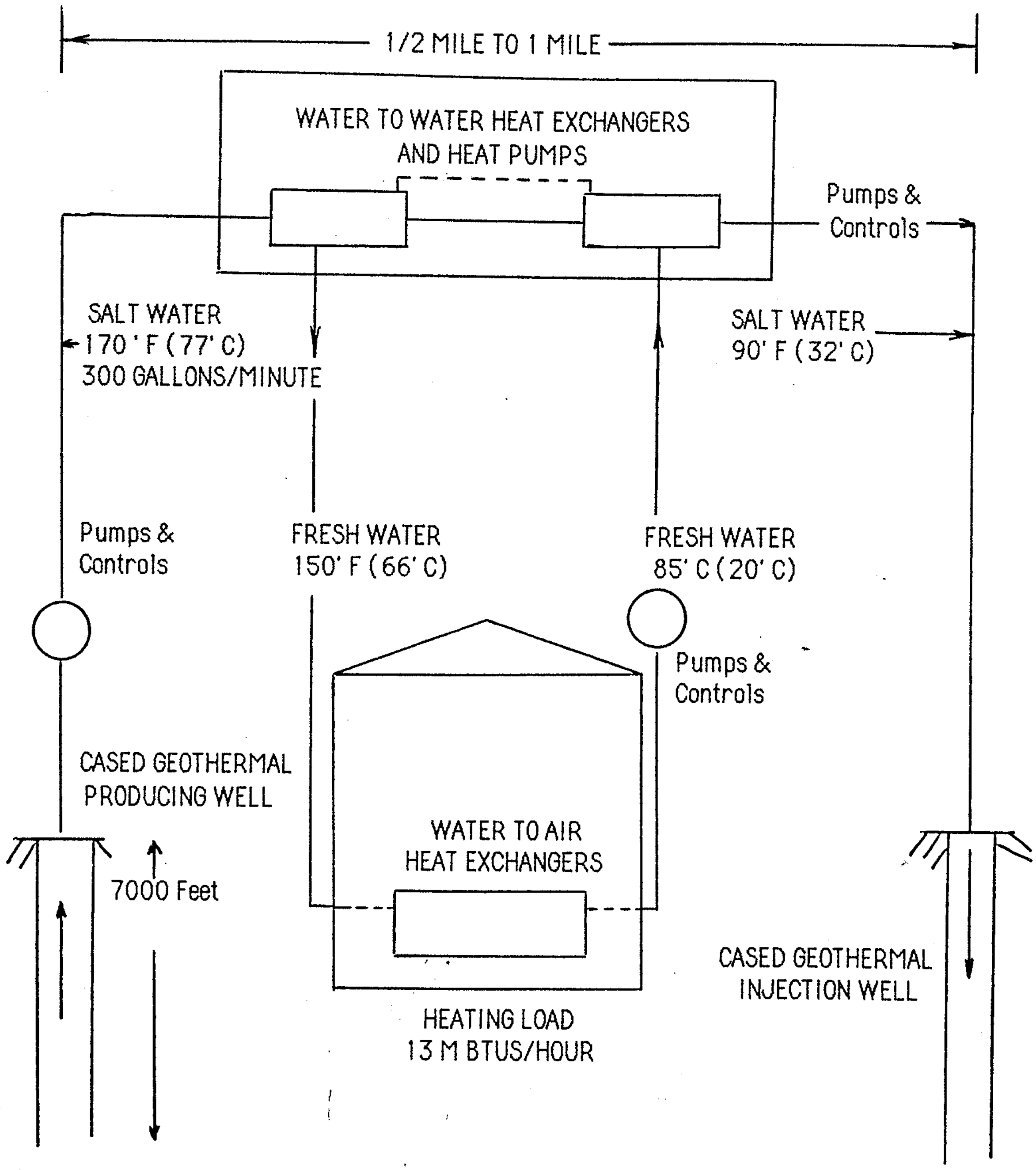


Figure 38: Schematic Diagram of Projected use of Low-grade Geothermal Energy

Source: Compiled from data in Handbook of Geothermal Energy, 1982.

Heating of the industrial and administration facilities would be through underground pipes to hot water radiators in each building.

The distribution lines, running 5000 feet, would be 5 to 15 inches in diameter consisting of asbestos-cement pipe insulated with polyurethane foam. Pumping of the water from the well and through the distribution system could be done by harnessing the wind or by using photovoltaic cells. Another 5000 feet of lines would be required to service the PMQ's. Figure 38 shows a simplified schematic drawing showing the components of a low-grade geothermal space heating system.

Geothermal energy available in Manitoba is not adequate for the generation of electricity (generally temperatures in excess of 180' C are required). Temperatures are thought to be suitable for space heating but detailed research has not been done to confirm this hypothesis. Costs of installation and providing heat are hard to identify and quantify due to the absence of concrete data. The University of Regina has undertaken a research project to tap hot water under the city contained in sedimentary rocks. One million dollars was the cost to drill to a depth of 2200 m. [90] To return the cooled water to the rock would require another well at a cost of one million dollars. The cost for pumps, the ancilliary equipment and annual maintenace would be small compared to the drilling costs, on the order of $250,000. From this analysis geothermal energy is not presently a viable alternative to the use of fossil fuels for space heating and generation of electricity.

BIOMASS

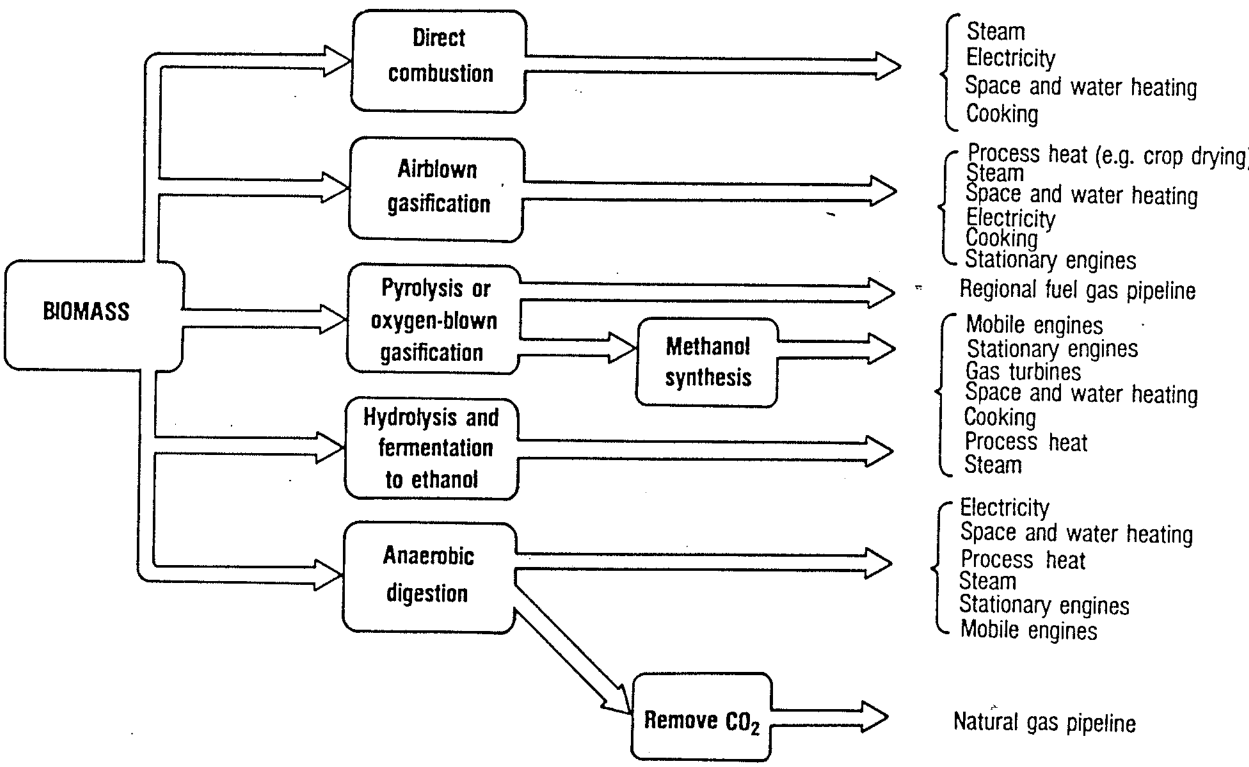
Biomass can be described as all plant and animal material which can be converted into energy. Generally it includes crop, forestry, municipal and livestock wastes and products grown especially for conversion to energy - wood, algae and kelp to name a few. Chapter two outlined the var ious processes used to convert biomass into energy: wet and dry conversion. Figure 39 summarizes the available direct-use applications.

As discussed there is a myriad of biomass available in varying regions of the world for conversion into energy. For our purposes i.e. Manitoba's climate, the number of sources available is greatly reduced. Examples of biomass available would be limited to municipal wastes both wet and dry, livestock wastes and short rotation forestry. Silviculture is not presently used but it is a viable option. End-use energy would be electricity and space heating. From this basis energy systems will be described.

The area around Gypsumville is the factor that will determne the viability of the systems chosen. This will also dictate what biomass is available, and what could be grown specifically for energy conversion.

Figure 39

FUEL USES FOR BIOMASS



Source: United States, Office of Technology Assessment, 1980a, p. 24.

The area is characterized by subsistence farming, cattle ranching and covered with scrub pine along with the Fairford River. There are small villages in the surrounding area limiting the amount of municipal waste that can be utilized; combining with the waste produced by the Station enough may be available for a small generating plant. Hauling distances would not be too great but economies of scale may not permit an efficient operation.

Silviculture

Silviculture is generally described as the growing and harvesting of biomass specifically for energy production. In this instance short rotation tree farming will be discussed. The technique is similar to agricultural crop growing like corn and sunflower. High yields, fertilization, harvesting and irrigation are all involved. Fast growing tree species like hybrid poplar, aspen and birch have good potential as alternate energy sources. In fact these are good choices as they are the main hardwoods of the prairies.

The process would involve the planting of saplings 0.3 - 2.0 m apart and in rows spaced about 1 m apart. The first harvest would be cut in four years. By this time the trees would have reached 5 m in height. The existing tree cover would be cut and used for energy production until the first group of trees had reached harvesting height. The most efficient plantation would contain six separate areas each with different stands of maturing trees. [91] The cutting would rotate from one area to the next as each stand reached its cropping height - normally after four years. The trees would be harvested by machines similar to cutting corn. The trees would be turned into chips for direct use in furnaces and the resulting stumps would resprout then be harvested in another four years. Yields have been estimated to be from 11 to 23 ovendry tonnes per hectare per year (20 dry t/ha-yr). [92] The yields would vary according to the amounts of fertilizer added, irrigation supplied and climate.

There would probably be up to 300 acres (121 hectares) of land available within the Station's boundaries for use as an energy plantation. In addition there are crown-owned lands surrounding the area that could be leased for a nominal fee to provide more land.

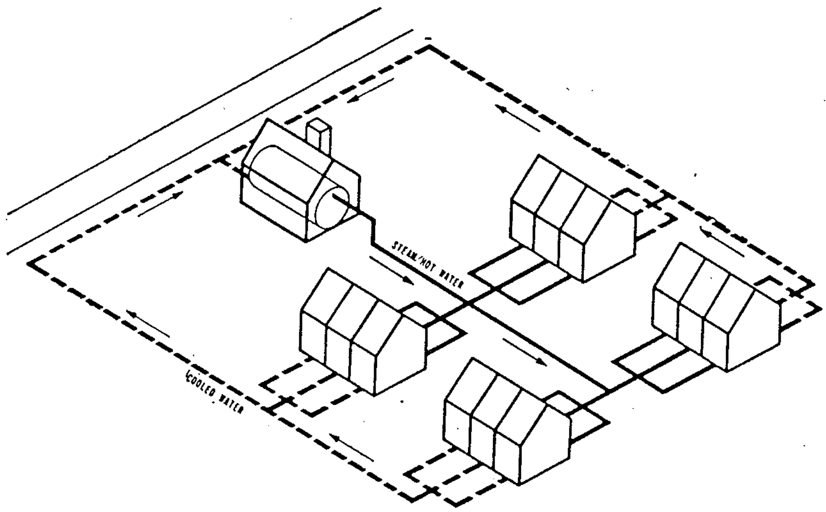
There are no tree plantations in operation that can be used as an example except those that have been theorized. Several models have been proposed that exhibit similar features. One such farm comprises between 21,000 and 50,000 acres producing 250,000 ovendry tons enough to support an electric power plant of 50 MW(e). Rotations are six years with five crops (one first growth and four coppice crops) being harvested during the lifetime of the farm. There would be 2,725 trees per acre. [93]

This farm is unfortunately too large for our small community but parameters can be extrapolated to approximate the size required. The peak requirement is for 2 MW(th) and 1.5 kW(e), 750 kW for the Station buildings and 750 kW (the MQ's would use wood burning furnaces). Using 1.5 MW(e) as the starting point the area required would 50 times less than the farm example or between 500 and 1200 acres. Direct combustion of wood is the best method in this case for producing energy as this technology is well proven. Figure 40 illustrates a proposed district heating scheme using direct combustion as the heat source. Also shown is a co-generation scheme utilizing a wood-fired boiler to produce electricity and space heating. Space heating is provided by either hot water or steam.

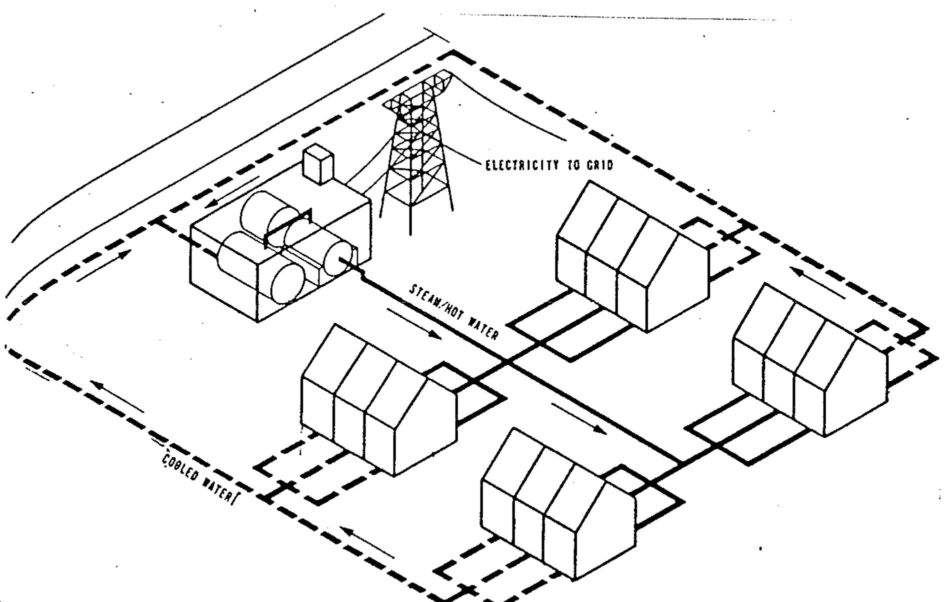
A greenhouse operation in Nova Scotia utilizes direct combustion to privide heat for its operation. The system used is a Swedish BRUKS wood combustor. A pre-combustion cell enabled the system to operate between 82 and 86 per cent efficiency using any type of wood with a moisture content between 30 and 60 per cent. With this new technology 2,600,000 litres of oil were displaced by burning 15,000 green tonnes of wood. Total cost of the installation was $973,000 with a payback period of 2.9 years.

Heating fuel usuage for the station and MQ's in 1984/85 was 1,570 K litres of oil which means that the BRUKS system could be used as a guideline when determining costs. Using the same system to generate electricity would require another 735 K litres of oil. Now what would this mean in terms of the amount of wood required: possibly 13,500 tonnes of green wood if compared with the BRUKS

Figure 40: Examples of Wood-fired District Heating/Cogeneration Systems



Wood-fired district heating system



Wood-fired electricity generating-district heating system

Source: Environmentally Appropriate Technology, 1978, pg 65.

operation. This quantity could be bought from outside agencies however if the intent is to be self-sufficient then the wood must be harvested and/or grown for this purpose. Approximately 1100 acres of land would be required.

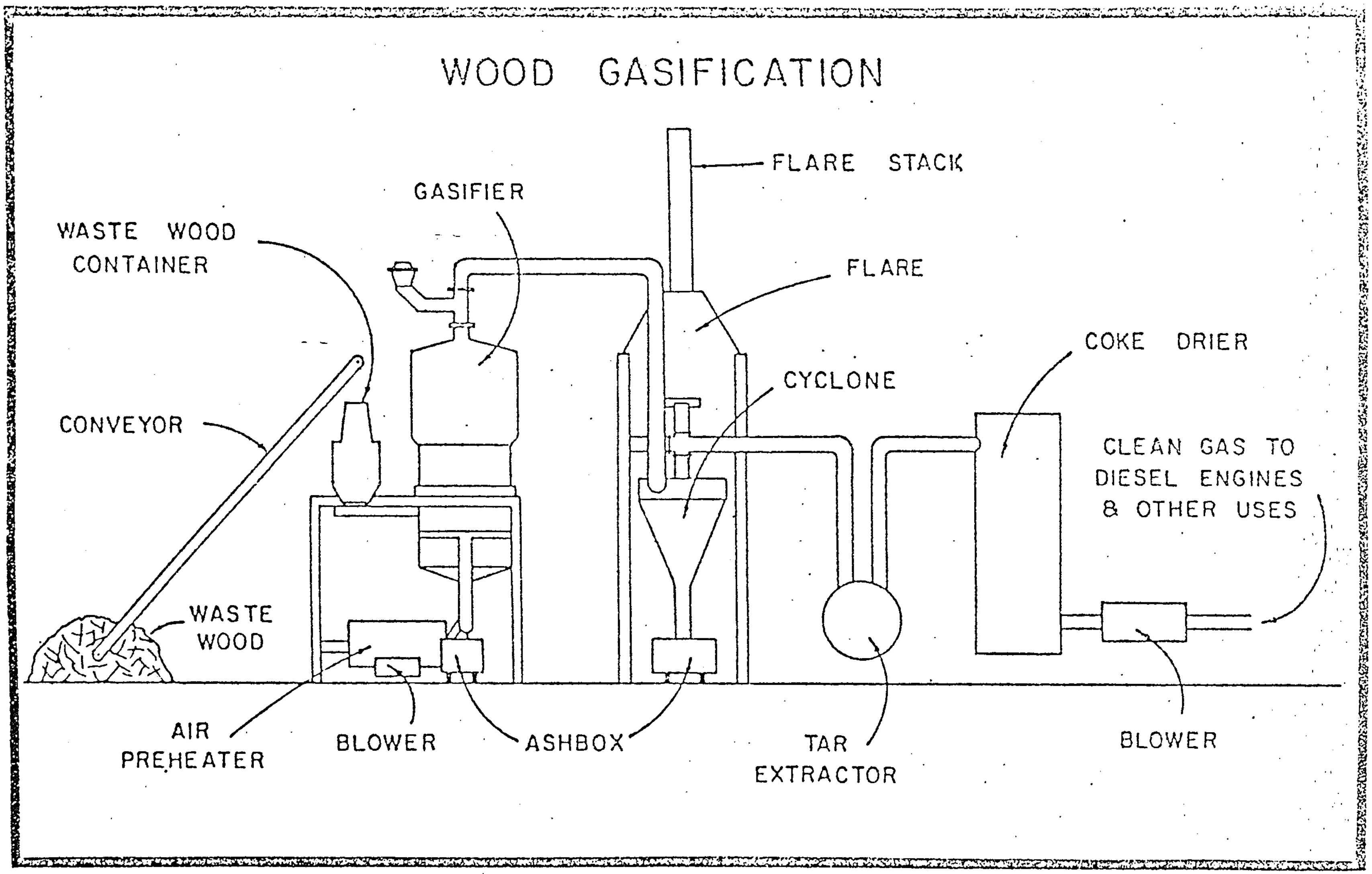
Gasification is another process that can be utilized. In fact a remote community in Saskatchewan uses a gasifer that converts wood into a gas that runs a modified diesel that powers a generator. Figure 41 details the components of a wood gasifier.

Municipal Solid Waste (MSW)

There are many examples of the use of MSW in the production of energy, steam for district heating and for electrical generation, but these occur mainly in the United States. The amounts of MSW required for these large generating plants range from 750 tons/day (tpd) to 3000 tons/day which are capable of producing 40 to 75 MW of electricity. Most of these facilities use the Swiss designed Von Roll reciprocating technology employing mass burning (with combustion at approximately 2,500 degrees.

A new process, the O'Connor Combustor (water-cooled rotary combustor), provides modules ranging from 60 to 500 tpd. [95] The system is designed to process agricutural, industrial and municipal solid wastes including materials with extremely high moisture content. Both these processes require large amounts of waste and are

Figure 41: Wood Gasification



Source: Saskatchewan Power Corporation, Evaluation of a Wood Gasifier at Hudson Bay, Saskatchewan, ENFOR Project C-8(1) quite costly, ranging from $8.4 million to $87.5 million. Unfortunatelythese units are too large to be employed in our case. However, as the technology is proven, these processes could be down-sized to meet our requirements. In fact, by combining tree harvesting with MSW, a viable system could probably be developed.

There is another system in operation today that uses smaller combustors that can be transported by rail or by tractor trailer trucks. The process is the modular combustion unit or controlled air incinerators that utilize a two-stage controlled air combustion process. These units come in various sizes up to 25 tpd. [96] This system has been designed to be used by small communities, hospitals and other small applications. As with the utilization of wood-fired boilers, incinerators can be used as the heat and electricity sources for a co-generation system.

There are several processes available today to transform MSW into energy but a detailed analysis is required to determine the most effective system for this application, however it is beyond the scope of this thesis.

Sewage

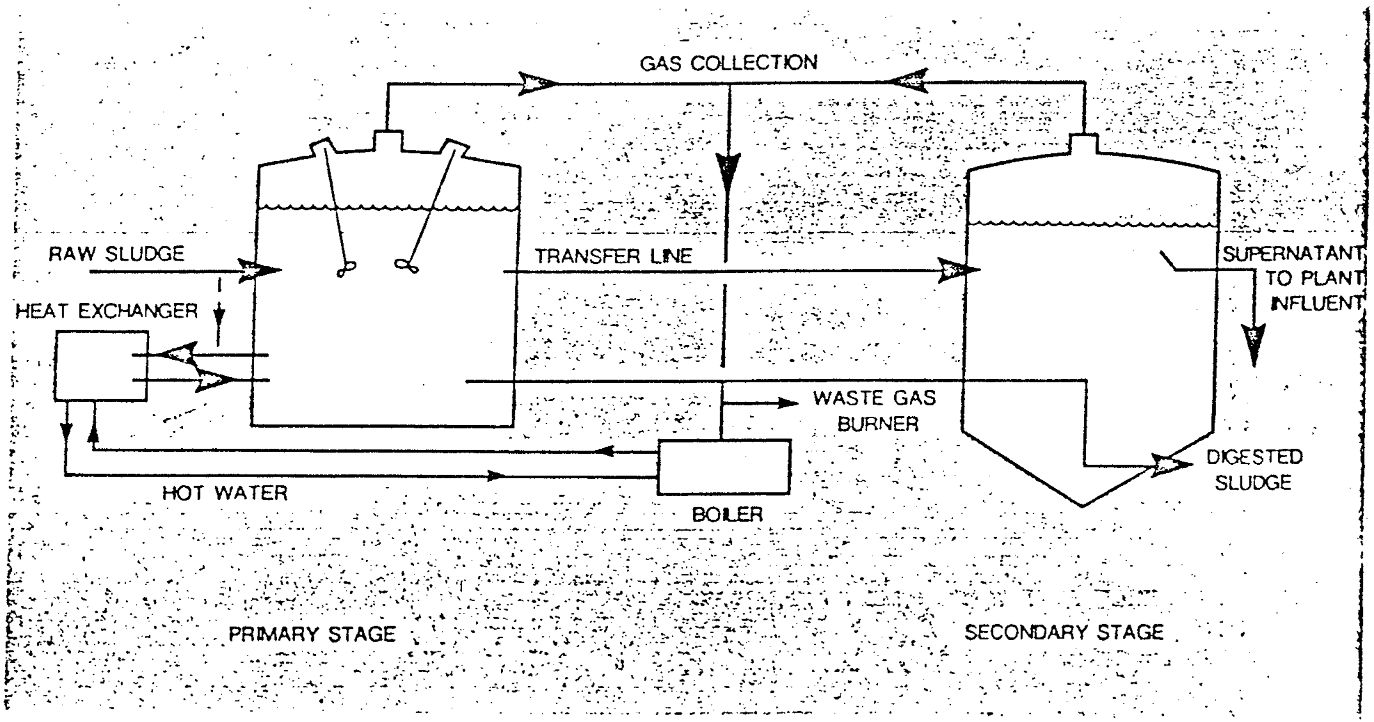
There is also an opportunity to utilize the sewage treatment plant as an alternate energy source. In this instance anaerobic digestion is the process that can transform sewage into a useable fuel i.e. biogas.

Basically a medium joule value biogas (energy value 60 % that of natural gas), methane, is produced that can be used as a fuel to produce steam and/or electricity. Also produced in this process is carbon dioxide and traces of hydrogen sulfide. Hydrogen sulfide is usually removed using ferrous oxide scrubbers but the carbon dioxide is left in it as it is expensive to remove. High compression spark engines provide the best method for burning this fuel. Anaerobic digestion has proven to work well with animal manures but there have been problems with sewage.

In fact the town of Orangeville, Ontario is using a cogeneration scheme to use the methane produced in their water pollution control facility. In use is a two-stage anaerobic digestion process to produce biogas, where the main component is methane. Figure 42 illustrates the anaerobic digestion system. Enough electricity is produced to operate the plant and the heat is sold to a nearby school and used in the plant building. The pay-back period for the capital costs of the system is estimated to be 6.5 years. [97]

Another method of converting effluent to a usable energy form, is by the process known as TOTEM - or Total Energy Module. It is a high-efficiency cogenerator producing 15 kW of electric power and 140 MJ of heat (hot water) at 85' C from a Fiat 903 cc engine utilizing biogas instead of gasoline. One engine would cost approximately $35,000. Most of the energy produced would be used to operate the

Figure 42: Typical two-stage anaerobic digestion system.



Source: ASHRAE JOURNAL February, 1986

treatment plant and provide heat. The more modules added, the more excess energy available to be used by other buildings. Just how much energy would be produced by the sewage plant has not been determined.

Summary

It has been shown that there are technologies available that can process biomass - municipal solid waste, sewage and wood - into heat and electricity. Our application, being small-scale, would seem to dictate that if two or three types of biomass could be combined and processed through one process it would be cost-effective to do so. There are many different systems on the market today that make it difficult to choose the best system without a detailed engineering analysis. However, the direct combustion process is still the most effective method of converting biomass into energy. The BRUKS system is one example of direct combustion that has worked. The Station requires approximately the same amount of energy as in the Nova Scotia example. The installed cost for heating would be $2 million with an average fuel cost of $200,000 per year.

FINANCIAL EVALUATION

In order to evaluate the various systems, other than ensuring they work, a financial review is usually undertaken. Generally this involves two methods; simple payback period and life-cycle cost analysis.

Simple payback is the length of time it takes to recover the cost of the system based upon the fuel savings achieved by the system. At some point in time the costs and savings equal out - this time is the payback period, usually given in years. The shorter the payback period the more economical the system becomes. This is the simpler of the two. Generally life-cycle analysis takes into account the cost of the system over its useful life including operating and maintenance costs. The present value of that cost is determined using present worth tables and then compared to other systems. The system with the lowest cost over the amortization period is the most economical. Specifically life-cycle cost can be defined as;

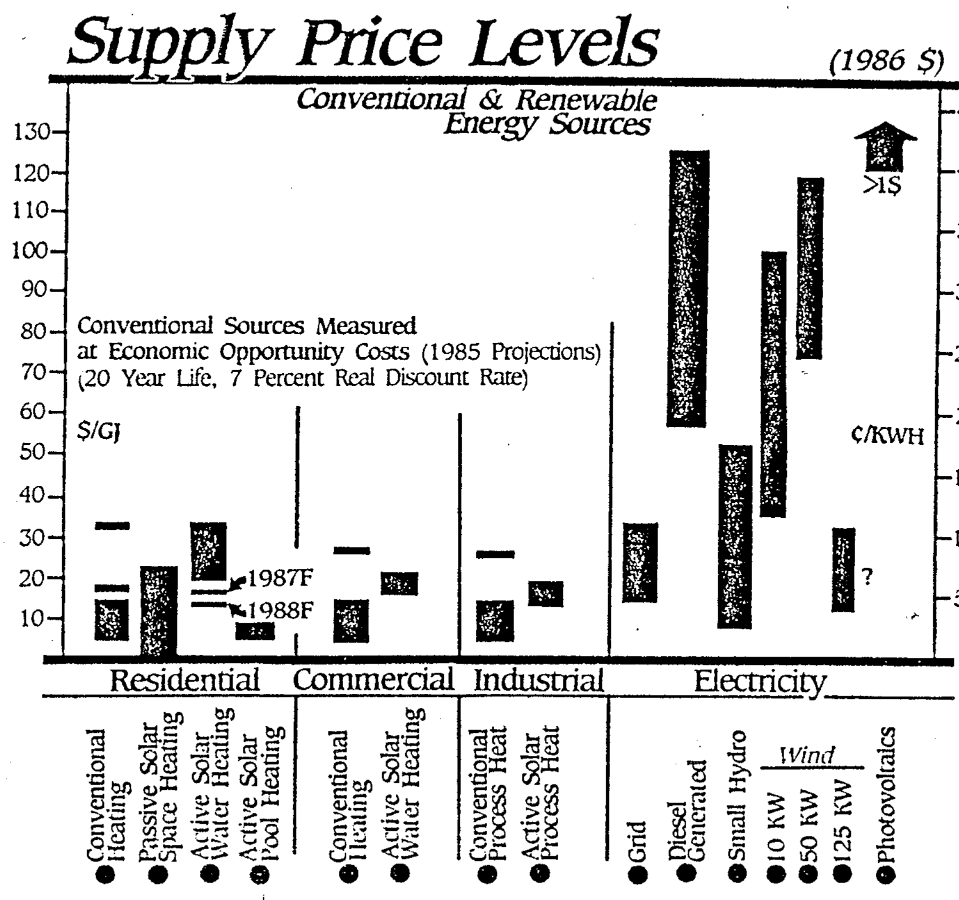
> "Life cycle cost is the total of all relevant costs associated with an activity or project during the time it is analyzed, including all costs of ownership, operation and maintenance. The *life cycle* is the period of time between the starting point and cutoff date of analysis over which the costs and benefits of a certain alternative are incurred. If life cycle benefits exceed life cycle costs, then the project is economically desirable." [98]

Another method, albeit not very statistical, is total cost. In this instance the system with the lowest total installed cost is the most economical. This can be used to initially rank the systems identifying those that merit further study and those that could be eliminated from the discussion. Specifically at some point, the alternate systems would cost more than an equivalent fossil fuel energy source. This is when life-cycle costing would become important. Energy costs can escalate rapidly, as they did in the late 70's, making the more costly options viable as the oil price increases.

Energy, Mines & Resources has recently analyzed the price levels of conventional resources and alternate energy sources available on the market. Figure 43 illustrates the comparison. In this case economic opportunity costs were calculated i.e. 20 Year life at a 7 percent real discount rate. The widest variation of costs is associated with the producton of electricity however diesel generation is compared favourably with wind power.

Ontario Hydro has recently done an analysis on costs, similar to EMR. They state that renewable sources of energy could play an effective supplementary role in future electricity generation, especially in remote areas where the 7.1 cents/kWh for photovoltaics and the 8.6 cents/kWh for wind are more economic than the minimum cost of 9.5 cents/kWh for diesel generation. Wood waste (7.3 cents) and wood chips (8.9 cents) were not expected to make a large impact. Current costs for fossil fuel generation include 4 cents for coal, 4.2 cents/kWh oil/gas generation, 3.9 cents for hydraulic and between 3.2 and 6.7 cents/kWh for nuclear. [99]

Figure 43: Supply Price Levels



Source: Energy Mines & Resources from SOL Vol. 54, 1986, pg 2.

Table 10 compares the cost of the various alternate energy sources that have been described previously. The costs displayed are the installed costs of the power sources not the life cycle costs. The only source where accurate figures can be presented is nuclear energy. This is due to the fact that a specific installation of a small reactor for a small remote community has been analyzed in detail.

Table 10 has detailed the total costs of the various alternate energy systems. At this point the cost of the present system should be examined. As the station was constructed in the early 60's, plant replacement values (PRV's) are used. The PRV of the Central Heating Plant, its two boilers and the two oil storage tanks is $2.0 million (in 1986 $). The PRV of the three standby boilers is $150,000. Electricity for the Married Quarters is provided by Manitoba Hydro (not costed) and heating is by individual oil-fired furnaces at a total estimated cost of $75,000.

Comparing the total cost of approximately $2.5 million with the values listed in Table 10 indicates that the existing system is more economical. However operating and fuel costs i.e. life cycle costs are not included as this information is not available for the other systems due to the lack of sufficient data to determine them.

TABLE 10: COMPARATIVE TABLE OF ALTERNATE ENERGY SOURCES

ENERGY SOURCE	SYSTEM INSTALLED COST[1]	
	HEAT	ELECTRICITY
Nuclear: Fission[2]	$4.0 M	$4.0 M
Solar: Active	$3.0 M	Not Viable
Passive[3]	.5 M	
Photovoltaics	$15.0 M	$15.0 M
Wind	$5.0 M	$5.0 M
Biomass	$2.0 M	$1.0 M
Geothermal[4]	$3.0 M	N/A
Nuclear: Fusion[5]	N/A	N/A
Existing Central Heating Plant	$2.5 M	Manitoba Hydro

NOTES :

1. Installed cost is approximate only based on best available information.
2. In the form of the SLOWPOKE 10 MW(th) reactor.
3. Costs based on building retrofit costs to upgrade to current energy standards.
4. Based on the assumption that geothermal energy is available (space heating only).
5. Nuclear Fusion is not technologically feasible at this time.

CONCLUSION

This chapter examined the various alternate energy sources - wind, geothermal, nuclear, solar and biomass - suitable for replacing fossil fuels. It was determined that the technology existed to utilize each alternate energy source as a producer of the two main forms of energy that were required for our case study, heat and electricity. Some of this technology existed only in the pilot plant stage, such as the SLOWPOKE reactor, while others were in widespread use, examples of which are direct combustion of biomass, wind farms in the United States, solar energy (both active and passive) and geothermal energy. Unfortunately most of the expertise and experimentation have taken place outside of Canada.

The wide variation in the cost data presented in Table 10 is due to the lack of data available in Canada necessary to fine tune the analysis and to determine life cycle costs. In the United States the emphasis has been on large scale installations in the areas of wind , geothermal and biomass energy. In these cases economies of scale come into play. A major negative impact has been dropping oil prices tied in with decreasing government incentives to make research into alternatives less attractive.

However a majority of these forms are not conducive to the Manitoba climate or its geography. in addition most applications have been developed on a large scale where economies of scale work well.

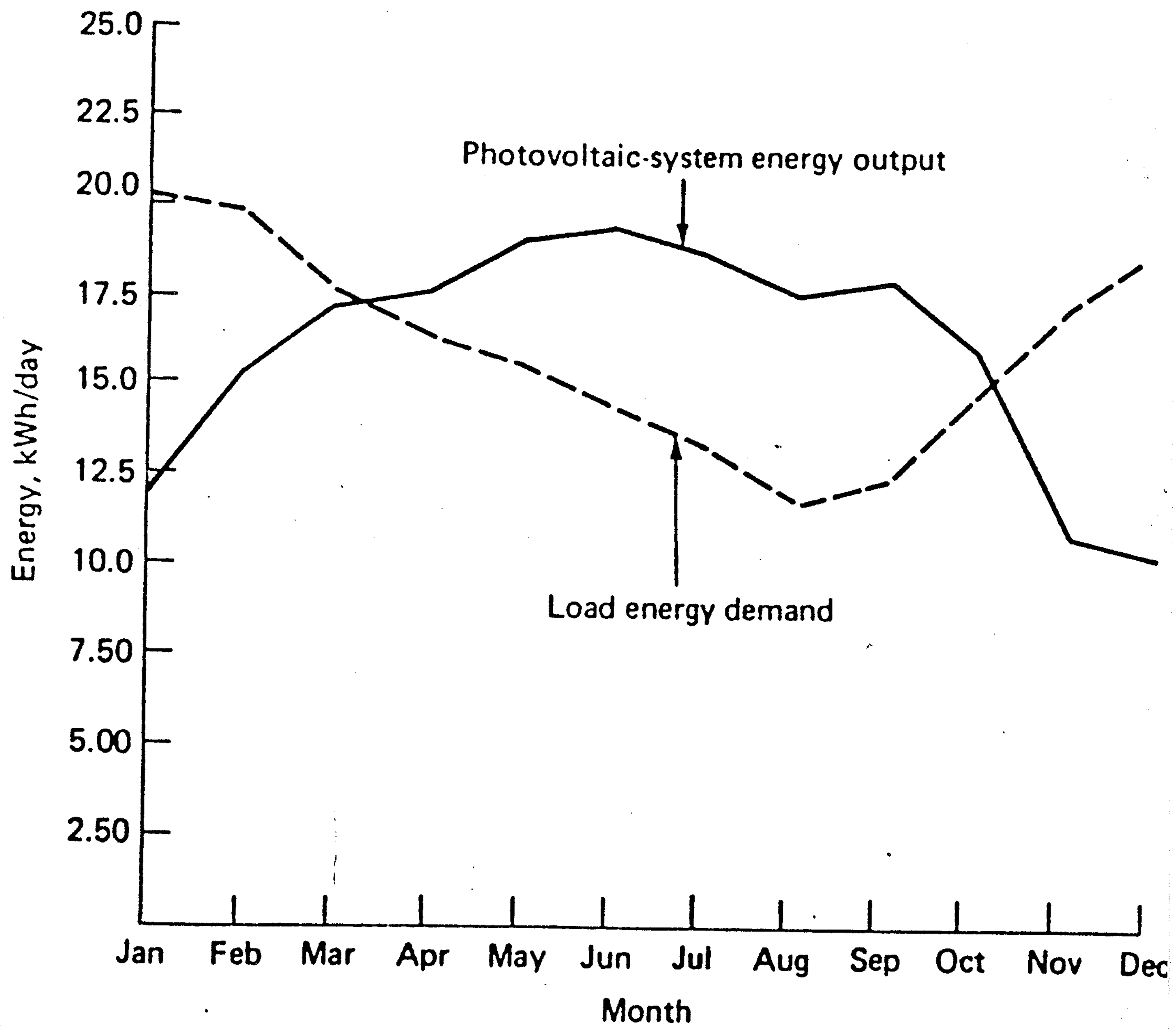
Climate is probably the biggest stumbling block in the utilization of these alternate energy sources. For example, with solar energy (whether active, passive or photovoltaic systems) the maximum amount of heat required is in winter when the amount of solar energy available is at its lowest point. In this instance as the systems are to provide 100 % of the total heat requirements seasonal storage is required. In most situations the the cost would be doubled.

In addition another limiting factor is the need for the provision of both heat and electricity. It is preferable to utilize the same system for both applications. This eliminates the need for duplication of effort; one system would be more economical to operate. Co-generation is the common term for this process.

Retrofitting the existing Station buildings and MQ's for energy conservation would be required regardless of what energy source is used. This can be easily seen by comparing the energy use for an 'ordinary' home to that of a super efficient home: it uses half the energy. Therefore the peak load would be reduced thus reducing the size and cost of both the energy and storage systems. This is important when considering that the highest load is mid January when the solar insolation is at its lowest. To note: the maximum PV system output equals the maximum load energy demand however not at the same time to be of any use. Figure 44 illustrates the imbalance.

Figure 44: PV System Energy Output vs Load Energy Demand

Source: Photovoltaic Energy Systems, pg 184.



This impacts directly on the costs of active solar and photovoltaic systems.

From this perspective the SLOWPOKE reactor would offer the 'best' chance of providing both the heat and electrical requirements of the Station. Direct combustion of biomass, a combination of MSW, sewage and wood from a tree farm, would also be comparable with the SLOWPOKE reactor along with wind energy. The use of geothermal energy and photovoltaics are neither cost-effective nor technologically advanced to be used on this scale at this time. Active solar energy combined with a district heating system is the third viable alternative.

AUTONOMOUSLY SERVICED SETTLEMENTS

CHAPTER FIVE

CONCLUSION

CONCLUSION

This thesis has concentrated on the theory that a remote settlement could be built and serviced with its heating and electrical needs by the use of renewable alternate energy sources. At the outset these energy sources were considered to be replacements for the nonrenewable fossil fuels such as coal, natural gas and oil that were being depleted at an ever increasing rate. The alternate energy sources chosen were solar, wind, biomass, geothermal and nuclear energy.

The original premise was built upon the article by E.A. Levin entitled "The Autonomous Community: City of the Future?" The preamble to the article provided the impetus: [100]

> There is growing recognition that the resources of the earth are not limitless, and we must learn to husband those resources far more effectively than we have so far been doing, if we are to continue to live on this planet. Accordingly, one of the objectives of the search for autonomous systems is the effective recycling of resources: their use, treatment and recovery, and their availability for use again.

An additional study, completed several years before, approached the same subject and asked the question - Can an autonomously serviced settlement be built in Canada now (1975), which would show that the energy and material basis of housing can be shifted from nonrenewable materials and resources to renewable energy and resources? [101] The answer at that time was an unequivocal yes. However the cost could not be predicted with any real accuracy and concluded that the proposed technology must be proven to be reliable and economically viable.

The oil crisis of the late 70's added impetus to the development of renewable alternate energy sources. Prior to this the price and supply of crude oil remained steady due to its control by the major oil companies. In the early 60's OPEC was formed primarily to wrest control of their oil reserves from the large multinationals. The net result was to substantially increase the price of crude oil on the world market. By the end of the 70's prices had escalated to over $40 per barrel on the spot market. As both the United States and Canada depended upon the importation of foreign crude, a crisis situation occurred. Estimates of reserves based on usuage projected the time when they would be depleted, early in the 21 st century. Conservation and the search for viable alternatives to crude oil progressed rapidly. The situation has now been reversed, prices are now down to $16 per barrel and OPEC has lost their dominant position. However research into and the development of alternate sources is still progressing albeit at a reduced pace. The estimates of the rate of depletion have been revised down, however the fossil fuels will become more expensive as they continue to be used and will eventually be depleted.

The question is not if but when will this point be reached? Governments must therefore be ready to ensure energy security for the future. Renewables then become of prime importance. Solar energy, wind energy and geothermal energy systems have been developed and are in widespread use today. In a majority of cases they are on an equal footing with the price of fossil fuels. These applications are more prominent in the United States, several Scandanavian countries, Japan and others. In Canada however developments are not as advanced as other countries. The major drawback in Canada is its climate rather than the lack of research and development.

This is especially true for solar energy. At the time when heating requirements are at their maximum the amount of solar radiation is at its minimum. This fact necessitates the addition of a seasonal thermal storage unit to any proposed solar system if 100 % of the heating load is to be provided. The generation of electricity by the use of photovoltaics is also affected as a greater collector area is required to offset the reduced efficiencies of the solar cells in cold weather.

This thesis has determined that the renewable energy sources will be able to provide the heating and electrical loads for a small community that are presently met by fossil fuels. This will especially be valid for remote communities far removed from main gas pipelines and hydro transmission lines that depend upon expensive diesel fuel.

The National Energy Program has stated that these communities would make ideal candidates for alternate energy. [102] This has been reinforced by a Special Commons Commitee in its report on Energy Alternatives. In addition a report by Adelaar and Associates on energy resources for the Northwest Territories concluded that biomass and wind were two alternate energy sources that could be used in many areas. [103]

A case study was used to determine whether or not this hypothesis was valid. It consisted of the analysis of the heating and electrical requirements of a small community, CFS Gypsumville, and the matching of alternate energy sources to meet the identified loads. Station buildings are heated by steam from diesel fuelled boilers and the MQs by individual oil-fired furnaces. Power is provided from Manitoba Hydro with a back-up system consisting of three oil-fired turbines. Three waste heat boilers, co-located with the turbines, are available but not in operation. This is in effect a co-generation system and it was utilized as such before electricity was provided by Manitoba Hydro.

The amount of solar energy falling upon Canada each day is equivalent to many times the generating capacity of our plants for one year. The problem is how to harvest this energy for useful purposes i.e. heat and electricity. Discussions centered on three ways to do this - active energy systems, passive energy systems and photovoltaics.

The technology is available, however there are disadvantages, most notably with that of cost and the Canadian climate.

Passive heating by itself, is not viable due to the construction of the buildings and MQs. However the buildings and PMQ's should be retroffited to reduce the energy usuage. This would include upgraded insulation and triple pane windows. Passive heating can be one of the best and least costly ways to utilize solar energy. If a new small community is in the planning stages passive heating features should be included in the design. Planners should ensure that the houses and buildings are orientated for maximum southern exposure. This is a no cost move that will pay dividends later. Other passive means should be considered along with building to Double E or R 2000 standards. This in effect gets back to what was discussed briefly in chapter two - that of energy conservation. District heating is another method of reducing energy consumption thus reducing the overall cost of the energy converson system. In looking at a new community or an existing one energy conservation should be the first aspect to be investigated and measures implemented to ensure this is of prime importance.

Photovoltaics can provide the electrical and heating needs of the Station however the cost of the solar cells would have to be significantly reduced before they would become viable for most situations although the price of diesel fuel in remote areas may partially offset the high current price. Figure 34, page 149 illustrated the present and future cost of solar cells. The other disadvantage is the reduction of efficiency during the cold winter months (typically by one-third) if the total load is to be provided, necessitating larger collector areas to offset the loss in efficiency. One large system for the Station would be proposed rather than individual units for each structure. Economies of scale would be realized along with the ability to control the peak loading to best advantage. The amount of solar cells required to provide the total heating and electrical load would cover an area of approximately 16 acres of land.

Active solar systems are available, both liquid and air based systems, to provide for the heating requirements (both hot water and heat) for the Station. Individual air-based systems would be appropriate for each MQ in that existing ductwork could be used for the distribution of heat. As there are no basements the installation of rock-bed storage units would be difficult but not impossible. On the other hand several liquid based systems providing heat to a group of homes or one large system would be more advantageous. This is the case since the existing roof area is too small and not strong enough to mount sufficient solar collectors to provide 100 % of the load. Either type of system could be used for the buildings.

Most research has centered on the use of these systems for individual residential homes and for small office buildings. Sufficient data is not available to effectively assess the viability of district heating systems using active means but economies of scale would dictate that they would be favourable. In addition active systems do not produce electricity so another alternative source is required. However the Soviet Union and Europe have had experience with this concept and it is accepted as the system to use for space heating on a large scale. In the planning of any new remote community these sytems should be carefully considered.

Geothermal energy cannot at this time be considered a viable alternative although the geology of western Canada is conducive to the discovery of low grade geothermal energy. Sufficient data has not been collected to adequately asses this potential. Extensive drilling would have to take place to verify the location of adequate sources. If a source is found, it would be used for space heating. Canadian experience in this area is very limited. It is expected that this form of alternate energy will be utilized in the future.

Wind energy is also a good candidate to supply the electrical and heating needs of the Station. Wind technology is well developed and a multitude of systems are available. The wind regimes in most parts of Canada are conducive to the production of energy from wind machines. The Station is located in a productive wind zone. An advantage over solar energy is the fact that the buildings and MQs do not have to be retrofitted in order to use this energy. Probably the only installation required would be those for the provision of electric heat.

Two types of wind turbines are being manufactured and installed for many applications in the world today: horizontal axis (HAWT), either two or three bladed propellor model; and, the vertical axis (VAWT), egg-beater style, wind turbines. In Canada the National Research Council and DAF-Indal are the prime proponents and developers of the VAWT system. Both systems have their advantages and as they are similar in performance the VAWT system is proposed as it is Canadian. Construction of a wind farm is proposed. The same problem, that being a requirement for a large land area to provide the necessary power, has arisen here as it has with solar energy. Most current wind systems feed directly into a power grid or are for individual structures.

The varieties and amounts of biomass available in the world are immense - they range from wood to MSW to algae. For this study the types available for energy conversion are limited to MSW and wood. MSW is generated by the residents every day and wood can be procurred from local sources or grown specifically in a wood plantation for harvesting. It is proposed that the two sources be used together to generate steam for space heating and electricity, in effect a co-generation scheme. Direct combustion is the most widely used method to convert biomass into energy followed by gasification.

Nuclear energy, in the form of the SLOWPOKE reactor, can be used to produce electricity and hot water for heating. This system has been used in several universities since the early 70's as a research tool. The technology is well-developed, it has been designed to be inherently safe and run unattended for long periods. An added advantage is the fact that the technology is strictly Canadian and its fuel is abundant in Canada. The one disadvantage is that the 20 kW university design must be enlarged and upgraded to the 2 MW(th) level. However AECL has developed a 2 MW(th) reactor which is presently being constructed a Pinawa, Manitoba. Their study has confirmed that the reactor will function according to design specifications and would produce energy at a cost equivalent to oil and enough to supply a small community with heat. In order to produce electricity along with heat a reactor with an output of 10 MW(th) would be required. It has also been estimated that if the price of diesel fuel reaches $1 per gallon then the payback period of the installaton would approach seven years. The success of this installation will ultimately determine the system's viability. The Northwest Territories government along with several other nations have expressed interest in the Slowpoke system.[104] Present indications are that the system will work and it is the preferred option.

Any alternate energy system that is developed for general use both in urban and remote areas must exhibit several features that will ensure that they will be successful. The following questions must therefore be answered in the affirmative: [105]

- Is it technically ready?;
- Is the market ready?;
- Is it environmentally acceptable?; and
- Is it cost effective from both a Government view and ultimately from a private point of view?

The systems that have been discussed as being appropriate alternate energy sources generally meet the requirements of the first three questions. The second question concerning the market has to be answered in two parts: these systems will not be used in urban areas as there is no market except for small installations of solar power in the form of hot water heating and passive heating; and, remote communities that depend upon diesel fuel are the markets that will see the use of alternate energy systems. Alternate energy systems are technically ready and environmentally acceptable.

The question of cost-effectiveness has not been fully answered due to the lack of sufficient data to accurately assess each system. This is due to the fact that there have been no large scale installations of alternate energy systems in Canada. Nuclear energy , in the form of the SLOWPOKE reactor, can provide both the electrical and space heating needs of CFS Gypsumville and many small remote communities. A 10 MW(th) reactor system would cost about $8.5 million and have a payback period of under seven years. Wind energy and direct combustion of wood and MSW would be the alternate choices for the provision of heat and power.

In fact Ontario Hydro has estimated that especially in remote areas the 8.6 cents/kWh for wind generation of electricity is more economic than the minimum cost of 9.5 cents/kWh. The only disadvantage is the need for a back-up system and the fact that wind has only been proposed for electrical generation rather than for space heating. To be economical the system would have to provide both.

Since these questions have been answered a checklist can then be developed that would assist planners in their investigation of both new and existing communities. A new community would be easier because all the inefficiencies of existing communities can be overcome.

Existing Community:

1. Is an energy conservation program in existence? Is it well publicized? Is it effective? Is energy conservation week successful?

2. Have houses been upgraded to current Double E or R2000 standards? Is there a government program available to assist in paying for the cost of upgrading? Is there a local by-law enforcing these standards? Is there a Northern Residential Standards program or by-laws in existence enforcing them?

3. Is the Town Manager conversant with the regulations? Are new sub-divisions planned with solar access and passive solar energy in mind, will buildings be properly orientated on the lot (see Mohammed, A. - Energy Efficient Housing Design)?

4. An energy audit should be carried out to determine the demand profiles i.e. to define the total energy picture for the community. Once completed, identify targets, evaluate alternate energy sources, develop a phased program for implementing selected projects; ensure follow-up action is taken?

5. Investigate topographic and climatic data to develop wind regimes, solar radiation and availability of biomass (wood, forest residues and peat) to determine the viability of these alternate forms of energy. Hire specialized consultants if required. Can district heating be utilized?

6. Can a load management control plan be put into effect, thus reducing the overall energy consumption?

New Communities

1. Carry out above first. Identify site. Then ensure new community is laid out with energy efficiency in mind; is it compact not spreadout thus reducing the length of distribution systems, in effect ensuring that a district heating scheme can be utilized ; are

sub-divisions and industrial parks on the east-west axis maximizing passive heating benefits; is there a master plan available outling zoning restrictions?

2. Ensure that Northern Residential Standards are the basis of new construction?

3. Industrial plants must conform to current energy standards?

4. Are climatic conditions and topography of the area conducive to alternate energy systems? Can the site location be varied to take best advantage of what is available?

As the price of oil increases to over $45 per gallon these alternate energy systems will become economical. The systems do work and they will be valuable tools in the development of future settlements in remote areas that would otherwise be dependent upon expensive diesel fuel.

FOOTNOTES

1 The National Energy Program, Report EP 80-4E, (Energy, Mines and Resources Canada, 1980), p. 66.

2 Housing with a Future, Roderick Robbie, Prime Consultant, (Central Mortgage and Housing Corporation, Ottawa, 1976), p. 1.

3 The National Energy Program, p. 53.

4 Remote Energy Use in Quebec. Paul Belanger, Transtec, (Energy, Mines and Resources Canada, Ottawa, 1982), p. 3.

5 Ibid., p. 1.

6 The Autonomous Community: City of the Future?, E. A. Levin, (Canadian Home Economics Journal, Spring 1980), p. 87.

7 Handbook of Energy Technology & Economics, Robert A. Meyers, (John Wiley & Sons, Toronto, 1983), p. 2.

8 U. S. Energy Resources, A Review as of 1972, M. King Hubbert, (Serial No. 93-40 (92-75), U. S. Government Printing Office, Washington, 1974), p. 11.

9 Handbook of Energy Technology & Economics, p. 1.

10 Ibid., p. 1.

11 Primary Energy Consumption 1983, BP Review of World Gas, (BP Gas Ltd., Britannic House, London, 1984), p. 2.

12 The National Energy Program, p. 2.

13 Ibid., p. 53.

14 *Resettling America: Energy, Ecology and Community*, Gary J. Coates, (Brick House Publishing Company, Andover, Mass., 1981), p. 521.

15 *Energy Futures for Canadians*, James E. Gander and Fred W. Belaire, (Energy, Mines and Resources Canada, Ottawa, 1978), pp. 290-297.

16 *Energy Alternatives:* Report of the Special Committee on Alternative Energy and Oil Substitution to the Parliament of Canada, (Minister of Supply and Services Canada, Ottawa, 1981), p. 10.

17 Ibid., p. 10.

18 *Handbook of Energy Technologies and Economics*, p. 621.

19 *Solar Engineering of Thermal Processes*, John A. Duffie and William A. Beckman, (John Wiley & Sons, New York, 1980), p. 432.

20 The buildings include the Denver and Colorado State House (CSU) II using air systems and the MIT House IV and CSU House I using water systems. Solar energy provided 25 per cent of the heating load for the Denver House and up to 75 per cent of the heating and hot water loads of the other three.

21 *Environmentally Appropriate Technology*, Bruce McCallum, Minister of Supply and Services, Ottawa, 1978), p. 20.

22 *Prospects for Solar and Wind Energy Utilization in Alberta*, E. J. Wiggins, (Alberta Energy and Natural Resources, 1978), p. 45.

23 *Energy Fact Book*, Department of the U. S. Navy, (Tetra Tech, Inc., Arlington, VA, 1979), p. 290.

24 *Solar Engineering of Thermal Processes*, p. 101.

25 *Energy Utilization in Alberta*, p. 13.

26 *Energy Alternatives*, p. 212.

27 *Solar Engineering of Thermal Processes*, p. 343.

28 The optimum capacity of an energy storage system depends on the expected time dependence of solar radiation availability, the nature of the loads to be expected on the process, the degree of reliability needed for the process, the manner in which auxiliary energy is supplied, and an economic analysis that determines how much of the annual load should be carried by solar and how much by the auxiliary energy source.

29 *Fundamentals of Energy Production*, p. 287.

30 *Energy Alternatives*, p. 217.

31 *Handbook of Energy Technology & Economics*, p. 664.

32 Ibid., p. 664.

33 *Fundamentals of Energy Production*, p. 155.

34 *Handbook of Energy Technology & Economics*, p. 663.

35 *Commercial Applications of Wind Power*, Paul N. Vosburgh, (Van Nostrand Reinhold, New York, 1983), p. 201.

36 *Environmentally Appropriate Technology*, p. 75.

37 *Energy Alternatives*, p. 222.

38 Ibid., p. 222.

39 Alternate Sources of Energy, No. 77, January, 1986, p. 36.

40 Alternate Sources of Energy, No. 79, March, 1986, p. 40.

41 Fundamentals of Energy Production, Edwin R. Harder, (John Wiley and Sons, New York, 1982), p. 160.

42 Energy Alternatives, p. 172.

43 Ibid., p. 172.

44 Energy Fact Book, p. 274.

45 Ibid., p. 267.

46 Handbook of Geothermal Energy, L. M. Edwards, (Gulf Publishing Company, Houston, 1982), p. 2.

47 Plate tectonics is the name for a theory which considers the outer layer of the earth to be divided into a dozen or more plates floating on a viscous layer.

48 Geothermal Energy in Canada-A Review of the Resources, Alan M. Jessop, (Proceedings of Energex 84, Pergamon Press, Toronto, 1984), p. 264.

49 Assessment of the Geothermal Resources of Atlantic Canada, Malcolm J. Drury, (Proceedings of Energex 84, Pergamon Press, Toronto, 1984) p. 285.

50 Geothermal Energy in Canada, p. 265.

51 Handbook of Geothermal Energy, p. 2.

52 *Energy Fact Book*, p. 253.

53 *Energy Fact Book*, p. 272.

54 *Handbook of Geothermal Energy*, p. 4.

55 *Energy Fact Book*, p. 274.

56 *Handbook of Geothermal Energy*, p. 5.

57 *Energy Fact Book*, p. 266.

58 *Biomass Energies-Resources, Links, Constraints*, Vaclav Smil, (Plenum Press, New York, 1982), p. 18.

59 *Progress in Biomass Conversion*, Kyosti V. Sarkanen, ed., (Academic Press, New York, 1982), p. 35.

60 *Fuel Gas Systems*, Donald L. Wise, (CRC Press Inc., Boca Raton, 1983), p. 5.

61 *Energy, The Biomass Options*, Henry R. Bungay, (Wiley Interscience New York, 1981), p. 6.

62 *Energy Fact Book*, p. 363.

63 *Environmentally Appropriate Technology*, p. 43.

64 *Energy Fact Book*, p. 367.

65 *Fuel Gas Systems*, p. 10.

66 Ibid., p. 10.

67 One pound of fissile material produces approximately 3 x 10^{10} Btu of energy (or 1 x 10^{7} kW-hr or 9 x 10^{12} calories).

68 Nuclear Reactor Engineering, Samuel Glasstone and Alexander Sesonke, (Van Nostrand Reinhold Company, New York, 1967), p. 23.

69 Ibid., p. 26.

70 Ascent, (Atomic Energy of Canada Ltd., Spring 1985), p. 14.

71 Small Reactors for Low-Temperature Heating, J. W. Hilborn and J. S. Glen, (Atomic Energy of Canada Limited, AECL Report 7438, 1981) p. 1.

72 Ibid., p. 3.

73 Ibid., p. 3.

74 Ibid., p. 5.

75 The reaction used here is the fusion of two hydrogen isotopes, Deuterium and Tritium, into helium accompanied by a release of tremendous amounts of energy. The basic form of the reaction is shown as:

$$^{2}D + {}^{3}T + \text{plasma energy} > {}^{4}He + {}^{1}n + \text{fusion energy}$$

76 Handbook of Energy Technologies, p. 559.

77 The Engineering of Magnetic Fusion Reactors, Robert W. Conn, (Scientifac American, Vol. 249, No. 4, October, 1983), p. 61.

78 The information contained in this chapter has been taken from the CFS Gypsumville Base Development Book (1981) and based on personal knowledge of the Station.

79 Energy Efficient Housing Design, A. Mohammed, Masters Thesis, (University of Manitoba, Winnipeg, 1980), p. 93.

80 Ibid., p. 93.

81 Solar Energy for Existing Housing, Robert W. Walford, Masters Thesis, (University of Manitoba, 1983), p. 149.

82 Ibid., p. 84.

83 Experience From Three Full Scale Solar Heating Plants, E. Gabrielson, Invited Paper, from Proceedings of Energex '84 (Pergamon Press, 1984), p. 563.

84 Handbook of Energy & Economics, p. 663.

85 SLOWPOKE 3 Reactor for Building Heating at CFS Alert, N.W.T., W.L. Wardrop & Associates Ltd., (Atomic Energy of Canada Limited, Chalk River, 1983), p. i.

86 Investigation of Alternative Energy Systems for CFS Alert, W. L. Waldrop & Associates Ltd., (Winnipeg, 1986) , p. 63.

87 Energy Alternatives, p. 223.

88 Exploring Energy-1:Wind Energy, Sean McCutcheon & Associates, (Minister of Supply and Services, Ottawa, 1981), p. 14.

89 Personal correspondance with DAF INDAL Ltd., June 1984.

90 Exploring Energy - 3: Geothermal Energy, Sean McCutcheon & Associates, (Minister of Supply and Services, Ottawa, 1983), p. 20.

91 Biomass Conversion Processes for Energy and Fuels, Samir S. Sofer and Oskar R. Zaborsky, (Plenum Press, New York, 1981), p. 84.

92 Energy, The Biomass Options, p. 30.

93 Ibid., p. 33.

94 Waste to Energy Project Updates, Donald Marier, (Alternate Sources of Energy, No. 77, 1986), p. 23.

95 Ibid., p. 26.

96 Energy and Resource Recovery from Waste, p. 149.

97 Cogeneration: A Volatile Solution, M. Donald Hum, (ASHRAE Journal, February 1986), p. 22.

98 Energy Alternatives, p. 95.

99 SOL, Vol. 55, September-October, 1986, p. 15.

100 The Autonomous Community, p. 87.

101 Housing with a Future, p.1.

102 The National Energy Program, p. 66.

103 Energy Demand and Supply in the Northwest Territories, Martin Adelaar, Energy Probe, (Adelaar and Associates, February, 1981), p. vii-ix.

104 Winnipeg Free Press, Saturday, March 29, 1986, pg 12.

105 Handbook of Energy Technology, V Daniel Hunt, (Van Nostrand Reinhold, 1982), p. 3.

BIBLIOGRAPHY

Acres Consulting Services Ltd., Overview Study of the Potential for Yukon Communities to Reduce Their Dependence on Oil, Energy, Mines and Resources Canada, Ottawa, 1983.

Adelaar, Martin & Associates, Community Specifac Energy Supply in the Yukon and North West Territories. (August, 1981).

Adelaar, Martin and Associates, "Energy Demand and Supply in the N.W.T." February, 1981.

Advertisement, Scientifac American, "Energy/Fuel/Power." Produced by Ruder, Finn & Rotman, Inc., Washington, D.C.

Alberta. Department of Energy and Natural Resources, ENR Report No. 89 "Prospects for Solar and Wind Energy Utilization in Alberta", (1978).

Atomic Energy of Canada Limited, Report AECL 6963, "Nuclear Energy: One Road to Self Sufficiency."

Atomic Energy of Canada Limited, Report AECL 7067, "Electricity/Oil Substitution."

Belanger, Paul, Transtec, Remote Energy Use for Quebec, Energy, Mines and Resources Canada, 1982.

Berkowitz, M.K. Implementing Solar Energy Technology In Canada. Energy, Mines and Resources Canada. Ottawa, 1979.

Brunner, Calvin R., and Schwartz, Stephen C. Energy and Resource Recovery from Waste. Park Ridge. N.J., Noyes Data Corporation, 1983.

Bungay, Henry, R. Energy, The Biomass Options. New York N.Y.: Wiley Interscience, 1981.

Canada. "Energy Alternatives." A Report by: The Special Committee on Alternative Energy and Oil Substitution. House of Commons, Canada, (1981).

Canada. Department of Energy, Mines and Resources. "The National Energy Program. 1980." Minister of Supply and Services, (1980).

Canada. Department of Energy, Mines and Resources, Report E1 78-8, "Energy in Canada: An Overview", (1978).

Canada. Department of Energy, Mines and Resources, Report M23-7/1981E, "Electric Power in Canada 1981" (1982).

Canada, Exploring Energy 1, Conservation and Renewable Energy Branch, Energy, Mines and Resources (1981), "Wind Energy."

Canada. Central Mortgage and Housing Corporation "Housing With a Future: A Preliminary Study of Autonomously Serviced Settlement in Canada." CMHC, Ottawa, Canada, 1976.

Coates, Gary J. et al. Resettling America: Energy, Ecology and Community. Andover, Mass.: Brick House Publishing Company, 1981.

Conn, Robert W., Scientific American, Vol 249, No. 4 (1983). "The Engineering Of Magnetic Fusion Reactors." 60-71.

Davis, W. Jackson. The Seventh Year: Industrial Civilization in Transition. New York, N.Y.: W.W. Norton & Company Inc., 1979.

Duffie, John A., Solar Engineering of Thermal Processes. Toronto, Ontario, John Wiley & Sons, 1980.

Duffy, John Q. "The Little Reactor That Can." Ascent Vol 3, No. 1, (1981), 1-6.

Edwards, L. M. et al. Handbook of Geothermal Energy. Houston, Texas: Gulf Publishing Company, 1982.

Energy Developments: New Forms, Renewables, Conservation. Proceedings of Energex'84. Regina Sask., 1984.

Fuller, Buckminster R., Ekistics 269, May 1978. "Energy Economics."

Gander, James E. and Belaire, Fred W., Energy Futures for Canadians, Energy Mines and Resources Canada, Ottawa, 1978.

Glasstone, Samuel and Sesonske, Alexander. Nuclear Reactor Engineering. New York. N.Y., Van Nostrand Reinhold Company, 1967.

Harder, Edwin L. Fundamentals of Energy Production. New York: John Wiley and Sons, 1982.

Harris, Norman C. Solar Energy Systems Design. NewYork: John Wiley and Sons, 1985.

Hilborn, J.W. and Glen, J.S. "Reactors: Best Heat Option." Energy Forum (Spring, 1982), 6-9.

Hilborn, J.W. and Glen, J.S. "Small Reactors of Low Temperature Heating", AECL 7438, Atomic Energy of Canada Limited, June 1981.

Hunt, V. Daniel. Handbook of Energy Technology. New York: Van Nostrand Reinhold, 1982.

Koeppl, Gerald W., Putnam's Power From the Wind. New York: Van Nostrand Reinhold, 1982.

Levin, E.A., "The Autonomous Community: City of the Future." Canadian Home Economics Journal, (Spring,1980), 87-89.

Littler, John and Thomas, Randall. Design with Energy: The Conservation and use of Energy in Buildings, Cambridge: Cambridge University Press, 1984.

MacIntyre, Linden. Ascent Vol. 3, No. 1, 1981. "Wind Power."

MacKillop, Andrew Ekistics 269, May 1978. "Conservation and Renewable Energy Options: Canada."

McCallum, Bruce, Environmentally Appropriate Technology. Ottawa, Ontario, Minister of Supply and Services Canada, 1978.

Meyers, Robert A., Handbook of Energy Technology and Economics. Toronto, Ontario, John Wiley & Sons, 1983.

Mohammed, A., Energy Efficient Housing Design, Department of City Planning, University of Manitoba, Winnipeg, 1980.

Montgomery, Richard H. and Miles, Walter F., The Solar Decision Book: A Guide to Designing and Remodelling for Solar Heat. San Francisco, John Wiley & Sons, 1982.

Morris, David J., Self-Reliant Cities: Energy and the Transformation of Urban America. San Francisco, Sierra Club Books, 1982.

Ophuls, William. Ecology and the Politics of Scarcity. San Francisco: W.H. Freeman and Company, 1977.

Pryde, Philip R., Non-Conventional Energy Resources. New York: John Wiley & Sons, 1983.

Sarkanen, Kyosti V., ed. Progress in Biomass Conversion. New York, N.Y., Academic Press, Inc., 1982.

Schiffman, Yale M. and D'Alessio, Gregory J., Limits to Solar and Biomass Energy Growth, Lexington, Lexington Books, 1983.

Smil, Vaclav., Biomass Energies-Resources, Links, Constraints. New York, Plenum Press. 1983.

Taylor, R.H., Alternate Energy Sources for the Centralised Generation of Electricity. Bristol: Adam Hilger Ltd. 1983.

UNIES Ltd., An Assessment of The Potential of Solar Energy in Manitoba., Prepared For: Manitoba Department of Energy & Mines, 1981.

U.S. Department of the Navy. Energy Fact Book. May 1979.

Vosburgh, Paul, N., Commercial Applications of Wind Power. New York: Van Nostrand Reinhold Company, 1983.

Waldrop, W.L. & Associates Ltd., "Slowpoke-3 Reactor for Building Heating at CFS Alert, N.W.T.: Technical and Economic Feasibility Study." Winnipeg, April, 1983.

Waldrop, W.L. & Associates Ltd., Investigation of Alternative Energy Systems for CFS Alert, Winnipeg, March 1986.

Walford, Robert, W. Solar Energy for Existing Housing. Masters Thesis University of Manitoba, 1983.

Wise, Donald, L., Fuel Gas Systems. Boca Raton, CRC Press, Inc., 1983.

Wyatt, Alan, Ascent Vol. 3, No. 3, 1982. "The Alternate Energy Scene".

PERIODICALS

Canadian

Ascent
Biojule
Canadian Renewable Energy News
SOL

United States

Alternate Sources of Energy
ASHRAE Journal
Futurist
National Geographic
Popular Science
Power
Solar Age
Scientifac American