A STRATEGIC RECONNAISSANCE LEVEL METHODOLOGY FOR ASSESSING POWER SUPPLY ALTERNATIVES FOR NORTHERN MINING

by

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ABSTRACT

A STRATEGIC RECONNAISSANCE LEVEL METHODOLOGY
FOR ASSESSING POWER SUPPLY ALTERNATIVES
FOR NORTHERN MINING

This study develops and tests a methodology that can be utilized for a reconnaissance level assessment of electric power supply alternatives for medium-scale mining in northwestern British Columbia.

The study is organized into four parts.

Part one characterizes the public planning framework of the study area. Present and future use trends of the region's natural resources, in particular minerals and energy, are reviewed, and a typology of public preferences for their development is established.

Part two carries out a literature-based review of the conceptual basis of normative decision-making. Specific energy project evaluation approaches are introduced. This establishes a theoretical framework for constructing the methodology.

Part three presents the energy project assessment methodology.

Part four applies the methodology to the RED-CHRIS deposit.

Salient features of parts three and four which form the core of the study, are outlined below.

Energy Project Assessment Methodology

The central part of the study proposes a strategic, reconnaissance-level methodology for evaluating energy supply alternatives for medium-scale mining. Its scope is defined by; a) inclusion of strategic elements such as emphasis on priorities, analytical continuity, robustness, and adaptiveness, and b) adoption of a reconnaissance approach which reflects
an intention to accommodate preliminary information at an appropriate level of complexity and comprehensiveness.

The essence of the methodology entails three inter-related components:

1) Core Information Environment - Identifies and focuses on defining the energy supply issues for a particular undeveloped mineral deposit.

2) Basic Evaluation Environment - Assesses the viability of potential alternatives through the application of multiple criteria and formal decision-making procedures.

3) Peripheral Evaluation Environment - Assesses strategic information which is independant of the focused problem, but can exert an influence on the outcome of both the core and basic environments.

Each component contains strategic data bases and analytical processes that assist the analyst to proceed from initial problem identification to selection of alternatives. Within and between the three structural components, information is refined in an iterative fashion. This maintains a current perspective on the problem environment and leads to a more confident appraisal of the favoured energy alternatives for a mineral deposit.

Case Study Analysis

RED-CHRIS copper-gold deposit situated southeast of Iskut was selected for a case study application of the methodology. Typical production schedules ranging from 8 to 20 years would require corresponding installed electrical capacity of 7.5 to 23.5 Megawatts.

Key points which emerged from an analysis of this deposit's energy supply alternatives form the mine planner's perspective are:

1) Interest groups concerned with planning, developing, or regulating energy supply for RED-CHRIS include:

   a) Mineral deposit owners whose objective it is to maximize profit
b) Societal interests whose objective it is to maximize economic, social and environmental well-being aspects of the project.

c) Public policy interests whose objective it is to maximize economic, political, and social welfare within national and provincial energy policy.

2) Energy supply candidates identified and examined, include: diesel-electric, high voltage grid extension, small-hydroelectric, coal and biomass-fired generation, natural gas, peat, geothermal, wind and solar.

3) Comparison of different small-scale energy applications for remote areas is made difficult because of technical, political, and environmental uncertainties.

4) Satisficing and Dominance can be successfully applied from the mine planner's perspective to key decision criteria to narrow the various energy supply alternatives.

5) Small-hydro is the most favourable alternative at this juncture, followed by diesel. Coal-fired generation and biomass are comparable, and may be more favourable than diesel under certain circumstances. Other alternatives are presently unsuitable.

General Conclusions

Application of the methodology is limited by the interaction between analytical design, available physical resources, and uncertainty in the operating environment, human values and external decisions.

The methodology appears sufficiently robust and comprehensive to be adapted to other deposits in the region. Commonly shared information requirements combined with the iterative nature of information processing, can be used to reduce the resource demands and improve the efficiency of subsequent applications.

Finally, it is recommended that the value sensitivity of the methodology be tested by applying it from more than one perspective to the same deposit.
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CHAPTER ONE
INTRODUCTION

1.1 INTRODUCTION:

Minerals, timber, fish, wildlife, and tourism resources of Northwestern British Columbia present potential social and economic development opportunities. Resources are largely undeveloped however, owing to their remote and inaccessible nature, combined with unfavourable economics, insufficient infrastructure, and small population base.

Government efforts to catalyze northwestern resource development have occurred most recently through the Interministry Working Group on Northwest British Columbia (1982), whose task it was to develop alternate government-initiated economic, social, and environmental strategies for responding to a range of anticipated development scales, timing and social preferences. Recently published studies of the Working Group concluded that the mineral resource sector exhibits the greatest potential for experiencing immediate growth with resultant major regional impacts.

The topic of this study concerns the problem of energy supply for mineral resource development. An energy focused study was chosen because lack of electrical power supply for major mining ventures in the northwest has repeatedly been cited as one of the major constraints facing mine development in the region (F.L.C. Reed and Associates, 1972; Ministry of
The Interministry Working Group on Northwest British Columbia (1982) has stated:

One of the principal constraints on the development of mining in the (northern) zone is the lack of large volume, low-cost, electric power. Metal and asbestos mines are relatively energy intensive operations and the cost of alternative energy sources is prohibitive. In order to overcome the power constraint to mineral development in the area, new options need to be developed and investigated. However, planning, regulatory, and construction lead time are such that work should start immediately to review the alternatives and recommend a strategy for implementation. (p. 131).

Two previous studies that dealt with the energy problem are Northwest Study (1977) by the Ministry of Economic Development which offered preliminary suggestions for power options for deposits known at that time, and a recent Northwest Task Force study prepared by B.C. Hydro (1983) which carried out a preliminary economic evaluation of a fairly narrow range of energy supply alternatives for a number of major mineral deposits primarily from a provincial power systems perspective.

The present study examines the energy supply problem from a more focused and applied public policy perspective by developing and applying an energy project evaluation methodology.

A practical aspect which influences the nature of this study is the existing Energy Project Review Process in British Columbia. The Utilities Commission Act SBC 1980 C60 Part 2 S16 regulates industrial projects where consumed energy exceeds 95 Megawatts continuous electrical supply, or electricity
generated exceeds 20 Megawatts installed capacity. Regulated projects are subject to the Energy Project Review Process, which provides for comprehensive public assessment of environment/resource/landuse, social/economic, and energy/economic/finance factors. Thus for major projects that fall within the regulations of the Utilities Commission Act, the public policy requirements have been well stipulated.

Most of the medium-sized potential mines in northwest British Columbia have estimated energy requirements that fall short of 20 Megawatts installed capacity, and thus are not candidates for regulation and public review by the Utilities Commission Act.

The methodology advocated in this study will permit preliminary evaluation of energy supply alternatives for these smaller, unregulated projects in a manner that brings together social and environmental considerations in the preliminary engineering project evaluation phase. Thus industry, government, and the public will have an informal process through which strategic consideration of energy alternatives for mining purposes may be achieved.

The study concludes by applying the methodology to RED-CHRIS, an undeveloped copper-gold deposit located centrally within the study area.

A major feature of this exercise will be the preliminary examination of ten energy supply technologies. The most favourable will be selected based on priority criteria which reflect the objectives of one of the key resource use
preference groups. Finally, improvements to the overall analysis will be suggested in order to better apply the analytical framework to other mineral deposits in the region.

1.2 RESEARCH OBJECTIVES:

The principal objective of this study is to develop and test a methodology that can be utilized for a reconnaissance level assessment of electric power supply alternatives for mine development in northwestern British Columbia.

The principal objective is pursued through the following sub-objectives:

1) To provide a synopsis of natural resource endowment in northwestern British Columbia with reference to public preferences and future use trends.

2) To review alternative scenarios for mine and power development in northwestern British Columbia.

3) To review literature on normative decision-making processes as a precursor to investigating evaluative processes and criteria specific to the range of public preferences on resource use identified in sub-objective 1.

4) To develop a methodology for reconnaissance level assessment of power generation alternatives for mineral development which incorporates the principles and criteria identified in sub-objective 3.

5) To test the methodology through a case study of a potential medium-sized mine, the RED-CHRIS copper-gold deposit.

6) To suggest further areas of research which will permit
an improved application of the methodology to other potential mines within the northwest.

1.3 RESEARCH ORGANIZATION:

The six objectives are addressed as follows:

Objectives 1 and 2 -

Chapter 2 reviews provincial and regional government studies commissioned over the last decade which reported on regional development of the northwest. These studies are augmented by various community, industry, and institutional sources, along with general mineral economic and energy forecasts, in order to obtain a general understanding of the patterns of regional resources development, and to identify the range of public interests involved. The nature of potential future mineral and energy development scenarios is presented and conclusions drawn regarding their individual characteristics and their interrelationships. Reasons are presented for concentrating the subsequent analysis on a group of potential mines which can be categorized as medium-sized.

Objective 3 -

Literature pertaining to normative decision-making is reviewed in Chapter 3. This establishes a conceptual basis for understanding energy project evaluation methods, and their specific criteria, that accommodate the previously identified range of public interests.

Objective 4 -

In Chapter 4 the concepts and principles presented in
Chapter 3 are combined with key elements of strategic choice analyses, to develop a methodological framework for strategic, reconnaissance level evaluation of energy supply alternatives for medium-sized mineral deposits. The major components of the methodology are highlighted together with diagrams illustrating the dynamic nature of their interrelationships and internal processes. Chapter 4 thus draws together the theoretical research aspects and sets the stage for examination of a case history.

Objective 5 -

Chapter 5 profiles the RED-CHRIS copper-gold deposit as researched from geological publications and company reports, as well as the writer's five field seasons experience engaged in mineral exploration on or adjacent to the deposit. A range of potential energy consumption corresponding to possible short- and long-term mining schedules is calculated from standard energy consumption data in the literature.

Application of the methodology proposed in Chapter 4 to RED-CHRIS is documented in Chapter 6. A comprehensive range of energy supply alternatives are identified and classified, and literature-based research of specific evaluative criteria carried out. The analysis is concluded with the most favourable alternatives identified through the application of formal multi-criteria decision-making procedures.

Objective 6 -

The final chapter summarizes the results of the study and analyses and proposes ways to improve the application of the methodology to other mineral deposits.
Figure 1. Study Area Location Map
CHAPTER TWO
A MINERAL AND ENERGY SYNOPSIS OF
NORTHWESTERN BRITISH COLUMBIA

2.1 PURPOSE:

The purpose of this chapter is to introduce mineral and energy resource development scenarios for northwestern B.C. through the following synopses.

a) A summary outline of the northwest region's primary resource sectors other than minerals and energy, to provide insights into the broad social, biophysical, and economic environment peripheral, but closely inter-related, to the mining and energy issues.

b) A focussed discussion of the mineral resource sector.

c) A focussed discussion of energy resources: in particular, their relevance to mineral resource development.

2.2 A MULTI-SECTORAL REVIEW OF NORTHWESTERN RESOURCES

Northwestern British Columbia represents the province's last truly extensive undeveloped region. The wilderness character of the region belies its important endowment of minerals, wildlife, hydroelectric and coal resources, and spectacular untrammelled landscapes containing such unique features as Mr. Edziza volcanic terrain and the Stikine River's Grand Canyon.

The thesis area shown on Figure 1 covers a diverse geography of nearly 150,000 km², extending westward from the
Omineca and Cassiar Mountain Ranges through the Stikine and Teslin Plateau, to the Coast Range Mountains and boundary with Alaska. Major rivers such as the Inklin, Stikine, Dease, and Iskut drain glacier-covered mountains, lowland muskeg, and semi-arid, tundra-like, to forested plateaux. Highway 37, extending northward from New Hazelton to Watson Lake in the Yukon is the primary lifeline for the remote and widely scattered residents.

The region's economic character and primary resources are as diverse as its landscapes. The remainder of this section will briefly discuss the forest, fish, wildlife, and human resource components and their anticipated future scenarios as background to the detailed mineral and energy synopses which follow.

Since the earliest contact between native Tahltan and Casca peoples and Russian, British, and American coastal traders, the region has relied on the export of its natural resources as the basis for its economic survival. Although a commodity shift has occurred from gold and furs to a present day emphasis on precious and base metals, industrial metals, and tourism, the basic premise of an export-oriented economy remains intact and is forecast to remain so into the foreseeable future (Interministry Working Group on Northwestern British Columbia, 1982).

From 1861 to the late 1890's the region experienced its first major influx of thousands of prospectors and miners
enroute to the placer gold fields along the Stikine, Dease, and McDame rivers. This rush was followed in 1897 by the discovery of gold in Atlin area streams, swelling the area's population to over 10,000. Up to 1945, 898,681 ounces of gold, with a present value of nearly $400 million, had been mined from the region (Holland, 1950).

Today around 3000 people, comprised predominantly of Tahltan and Casca descendants and miners, reside in the widely scattered communities of Cassiar, Atlin, Dease Lake, Telegraph Creek, Eddontenajon, Iskut, Glenora, and Bob Quinn. Population growth is tied closely to sustained resource development and tourism, and has tended to proceed slowly and erratically. Recently, young homesteaders seeking alternate lifestyles and a resurgence of placer mining activity in the historic gold camps have increased local populations in such areas as Telegraph Creek and Atlin. Nevertheless, while mineral exploration and mining development, highway construction and maintenance, and tourism services continue to be the mainstay of local employment, they all suffer from being acutely seasonal in nature.

The Northwest Report (1977), Northwest Region Study of the Interministry Working Group (1982), and publications of Friends of the Stikine and Residents for a Free Flowing Stikine, all concur that diversification of the local economy to increase greater year-round employment is a high priority among residents. At the same time, however, residents are cognizant of the need to balance their desire for greater
economic prosperity and the ensuing social and environmental changes with the possible diminishment of the quality of wilderness lifestyle and sense of community. Residents will be challenged to respond creatively to the changes that increased resource sector activities will impose on the region.

Forest resources of the study area belong to the Cassiar Timber Supply Area (T.S.A.). Timber inventories are presently being refined. Previous studies indicated forest resources to be primarily of non-commercial value owing to prevalent overmature and decadent timber (Ministry of Economic Development, 1977; Interministry Working Group on Northwest British Columbia, 1982). Other studies indicate, however, interspersed localized areas of moderate to high value timber along the lower and middle sections of the Stikine River, lower Klappan River, and upper Skeena River (Forestal International, 1980; ELUC Secretariat, 1976). For example, land within the former Stikine and Klappan Public Sustained Yield Units (PSYU's), now redesignated part of the Cassiar TSA, encompassing 3,852,000 hectares contains 106,953,000 m$^3$ (110 m$^3$/ha) merchantable timber.

Part of the Stikine, Nass, and Iskut drainages, and Liard Plain support a number of small dimension lumber operations dependent on local demand. Overall, however, severe biophysical and climatic constraints combined with a lack of infrastructure, principally in the transportation sector, hinder short to medium term harvesting options. The
Interministry Working Group on Northwest British Columbia (1982) considered these constraints and was led to forecast relative stability in the forest sector. This can be interpreted to mean that for the foreseeable future the lumber industry will respond primarily to levels of local economic activity. As a result, the forest sector will remain small and likely be unable to respond to lumber demands of major development projects, such as mine developments, with the result that lumber would be procured from outside the region.

Advances in wood processing technology and new product development may result in unforeseen future utilization of presently low value timber or noncommercial species such as cottonwood (Populus balsamifera trichocarpa sp.), thereby expanding forest sector activities.

Wildlife is a multifaceted renewable resource of the north. Vast forestlands, of equivocal commercial value, in combination with adjacent wetlands and alpine areas create many diverse wildlife habitats. Varied biotic zones support major species such as moose, Osborn's caribou, mountain goat, sheep, grizzly and black bear, beaver, wolves and wolverine, as well as numerous resident and migratory bird species.

Wildlife productivity rates are typically low, but substantial populations of nearly all species have been maintained by virtue of their remoteness in comparison to greatly diminished wildlife populations prevalent in accessible parts of the province. Wildlife use and benefits in the north
include: its use as a traditional food source, cultural
inspiration for native people, tourist and big game hunting
attraction, revenue source through trapping, and its
contribution to natural ecosystem balance and natural heritage
or scientific study.

Wildlife's economic contribution to the region's economy
is aggregated with values for the entire Omineca-Peace
Management Region, and cannot be easily disaggregated for the
present study (Fish and Wildlife Branch, 1983; 1984).
Nevertheless, the Interministry Working Group on Northwest
British Columbia (1982) has indicated that the total
contribution by guide outfitting and trapping, generally within
the study area, may exceed $1 million per annum.

Recent studies by Williams (1982) in British Columbia and
Fox et al. (1983) for the Yukon have concluded that wildlife
diversity and preservation can be achieved by conservative
management regulations, protection and maintenance of habitat,
and appropriate institutional arrangements coupled with a
commitment of political will.

Impending developments in the northwest primarily in the
mining and tourism sectors will increase access for hunting and
wildlife viewing. The future of sustained wildlife populations
in the northwest, therefore, appears to hinge on the embodiment
of the substantive elements outlined by Williams and Fox et al.
The inevitable alternative is to experience a general decline
in wildlife.
Northern fishery resources experience similar developmental pressures and management issues as those experienced by wildlife. Extensive riverine and lake systems support significant populations of resident and anadromous species of rainbow trout, dolly varden, whitefish, grayling, and salmonids. Fish form an important staple of many northern diets. Sport fishing, and to a lesser extent commercial salmon fishing, are expected to increase in proportion to increasing resident populations, tourism, and new access opportunities.

The nature and extent to which industrial developments affect aquatic habitats will have to be determined by a careful weighing of the costs and benefits associated with preserving an acceptable level of fish habitat and populations.

Spectacular scenery, uncrowded landscapes, exceptional wildlife viewing, and unsurpassed sport fishing are among the outstanding attributes that attract a steadily growing number of tourists to the northwest. Growth of this sector in the last decade has been such that it is now second in importance to the mining industry. Three identifiable reasons contributing to this increase are: upgrading of Highway 37 as an alternate route to the Yukon and Alaska; marketing of Atlin as a tourist destination offering wilderness oriented, cultural and historical activities amidst spectacular scenery; and, wilderness tours in adjacent Mt. Edziza and Spatsizi Parks.

The region boasts five major parks, all currently devoid of road access. These are: Atlin Park (271,139 ha), Boya Lake Park (4597 ha), Mount Edziza Park (232,695 ha), Spatsizi
Wilderness Park (675,024 ha), and adjoining Tatlatui Park (105,825 ha). Park use data are generally not available or incomplete (Selby, pers comm.). Man-made facilities are restricted to several motel and campground operations along Highway 37 and in the Atlin area. Table I presents campground day and overnight use data for two popular Parks along Highway 37. The limited season during which these facilities are occupied has served as a deterrent to further major private sector investment for increasing capacity. However, recent promotion of Atlin as a winter cross-country ski destination may provide the impetus to expanding that community's accommodation sector.

Additional constraints to tourism expansion cited for the region include lack of access, lack of knowledge by non-residents of attractions, competition for tourism from other areas, possible local apprehension about outsiders, and lack of local funding available to construct new facilities.

While there is an overall lack of data regarding tourism to permit economic analyses and to distinguish trends in specific use categories, the volume of tourists is anticipated to grow in the future through greater access possibilities, marketing, and other strategies and spinoffs of regional growth. For example, the Interministry Working Group on Northwest British Columbia (1982) forecasts expansion of the tourism economy to average 3.5% per annum in the short to medium term.

This growth also appears predicated on the continued
availability of a variety of wilderness oriented recreation opportunities. To ensure that future options for tourism are available, participants in providing tourist services will require active involvement in major resource development and access proposals.
TABLE I.

Boya Lake Park and Kinaskan Lake Park

Use Data - 1979 - 1984

<table>
<thead>
<tr>
<th>YEAR</th>
<th>PARK</th>
<th>CAMPGROUND/OVERNIGHT (Parties) (# Visitors)</th>
<th>DAY USE (Parties) (# Visitors)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1979</td>
<td>Boya</td>
<td>1361 4355</td>
<td>974 3409</td>
</tr>
<tr>
<td></td>
<td>Kinaskan</td>
<td>n.d.</td>
<td>n.d.</td>
</tr>
<tr>
<td>1980</td>
<td>Boya</td>
<td>1245 3984 (May-Sep)</td>
<td>980 3430 (May-Sep)</td>
</tr>
<tr>
<td></td>
<td>Kinaskan</td>
<td>n.d.</td>
<td>n.d.</td>
</tr>
<tr>
<td>1981</td>
<td>Boya</td>
<td>1824 5836 (May-Sep)</td>
<td>850 2975 (May-Sep)</td>
</tr>
<tr>
<td></td>
<td>Kinaskan</td>
<td>3287 10,518 (May-Sep)</td>
<td>456 1596 (May-Sep)</td>
</tr>
<tr>
<td>1982</td>
<td>Boya</td>
<td>1585 5072 (mid May-mid Sep)</td>
<td>1068 3738 (mid May-mid Sep)</td>
</tr>
<tr>
<td></td>
<td>Kinaskan</td>
<td>3218 10,298 (Jun-Sep est.)</td>
<td>1026 3591 (Jun-Sep est.)</td>
</tr>
<tr>
<td>1983</td>
<td>Boya</td>
<td>1292 4134 (Jun-Sep)</td>
<td>2494 8729 (Jun-Aug)</td>
</tr>
<tr>
<td></td>
<td>Kinaskan</td>
<td>2401 7683 (Jun-mid Sep)</td>
<td>3111 10,888 (Jun-Aug)</td>
</tr>
<tr>
<td>1984</td>
<td>Boya</td>
<td>1227 3926 (Jun-Jul)</td>
<td>2788 9758 (Apr-Jul)</td>
</tr>
<tr>
<td></td>
<td>Kinaskan</td>
<td>1790 5728 (Jun-Jul)</td>
<td>2706 9471 (May-Jul)</td>
</tr>
</tbody>
</table>

Source: Courtesy of Donna Selby, Ministry of Lands, Parks and Housing

Kinaskan Park not recorded in 1979, 1980.
2.3 PUBLIC PREFERENCES AND RESOURCE USE

A foremost exercise in managing for resource use in any region is understanding the interests of resident individuals and groups, as well as interests of non-resident individuals and groups, who may or may not derive their livelihoods from within the region. The importance of this exercise is that it permits the objectives of the various interest groups to be identified and priority management and policy issues to be clearly focused. Rigorous examination of the consequences of newly proposed policies, resource use regulations, and development projects in light of these identified objectives promotes an understanding of the distributional effects of actions and therefore aids the decision maker's attempts to consider issues of equity as well as efficiency.

Public views differ widely on the appropriate uses of the northwest's myriad and commonly underutilized resources. To date, no formal survey has been carried out to define the views and preferences of resident and non-resident interest groups. Nevertheless, on the basis of several recent reports (Ministry of Industry and Small Business Development, 1983; Northwest Development Centre, 1982), and by comparing the region with existing studies from other northern jurisdictions (see for example, Freeman, 1981; Alaska Highway Pipeline Panel, 1979; Berger, 1977; Westwater Research Centre, 1981), it is possible to define the range of differing regional views. Four major, identifiable preference groups emerge as outlined below.
Group A - Status and Non-Status Indians comprise over one-third of the study area population in several reserves and widely scattered individual settlements. Native Indians are engaged predominantly in seasonal commercial enterprises including fishing, big-game and tourist guiding, agriculture, and subsistence hunting and gathering.

These people have an inseparable relationship to the land and its renewable resources which provide them with sustenance and their religio-cultural inspiration and heritage. They have not signed treaties with Provincial or Federal governments to date (see the 1910 Declaration of The Tahltan Nation in Appendix 1). Native people express their views on resource development and management from this perspective. In particular, they feel that the decision-making process for resource management must recognize their claim to aboriginal rights and explicitly acknowledge their responsibilities and roles in resource allocation activities (Ministry of Industry and Small Business Development, 1983).

Justice Berger's summary of native concerns in his Report of the MacKenzie Valley Pipeline Inquiry (1977) appears to reflect like sentiments of northwest B.C. native Indians,

Their concerns begin with the land, but are not limited to it: they extend to renewable and nonrenewable resources, education, health and social services, public order and, overarching all of these considerations, the future shape and composition of political institutions in the North (p. 163).

Group B - This group consists almost entirely of non-Indian residents who reside predominantly in the settlements of
Cassiar, Dease Lake, Bob Quinn, and Atlin. They generally derive their livelihoods from owner/operated commercial services, highways construction and maintenance, mining, and seasonal mineral exploration, tourism, and forestry activity.

The perspective of this group on resource development has been summarized by the Interministry Working Group on Northwest British Columbia (1982).

Industrialization and development from the mid-sixties onwards grew within the framework of reliance on resource industries for employment opportunities. The instability of the resource industries has resulted in a desire for further growth based on economic diversity.

Generally, the communities in the Northwest favour enterprises which increase the employment rate rather than those resulting in a large influx of population. They also favour enterprises which add substantially to the tax base, and retail, trades, and service enterprises which fill gaps in the business structure. However, there is a widespread concern, throughout the region, that additional growth not create environmental problems (p. 27).

Group C - A small but growing number of non-Indian residents in such communities as Telegraph Creek and Atlin have moved to the region to pursue alternate wilderness lifestyles predicated on a combination of subsistence and non-consumptive wilderness oriented commercial activities and services primarily in the tourism and arts/crafts sectors. The basis of their wilderness lifestyles reflects a cautious approach to resource use. Nevertheless, these residents have expressed a desire to stabilize and diversify local economies as a step towards enriching community vitality (Ministry of Economic Development, 1977; Friends of the Stikine-Newsletter 1, 1980).

Group D - The final group of interests include resident and
non-resident participants in mineral, timber, and energy resource development activities. Their interests generally favour policies advocating expansion of regional economic opportunities related to resource extractive industries, and they are active proponents of improved transportation, energy supply, and settlement facilities.

This group of interests has been mirrored in the 'strategy for development' which is advocated by the provincial government's Cabinet Committee on Economic Development in their Regional Economic Development Study, 1982.

Tourists comprise a fifth group whose interests contain elements of the previous four categories. Tourist preferences range from those who desire to experience, and see maintained, intact, unspoiled landscapes devoid of industrial development, to those who desire to experience outdoor, historical, and cultural activities while having the benefit of improved highway and community services.

To summarize, public preferences pertaining to the renewable and non-renewable resource economy in the northwest are as diverse as the resources themselves. They include unresolved aboriginal land rights of native peoples, economic diversification interests of non-Indian residents, resource extraction interests of mining, timber and utility corporations, as well as government socio-economic development objectives.

This diversity of preferences can be conveniently categorized by resource use preference sets developed by Eyre
for a study of Yukon water resources by Westwater Research Centre (1981). One end member of the preference set range reflects views "designed to foster a rapid rate of economic development", while the other end member reflects the views of those who desire "a relatively slow pace of economic development in order to assure preservation of the quality of environment". The remaining preferences share elements of both end members.

While the priorities and preferences of northwestern B.C. interest groups display fundamental differences which will not always allow issues to be reconciled, it is, nevertheless, within this context that resource allocation decisions and their respective tradeoffs must be made.
2.4 MINERAL DEPOSITS:

2.4.1 DISTRIBUTION

Base metal and industrial mineral deposits in the thesis area are distributed as shown on Figure 2. Deposits shown are those which have experienced advanced exploration, therefore permitting reliable measures of inferred grade and tonnage and calculations of in-situ value of contained metal. Additional mineral showings and prospects at early stages of exploration are not shown. High mineral potential areas representing favourable geological environments for discovery of additional deposits are indicated by the shaded pattern in the figure.

Four major northwest trending tectonic belts encompass six principal geographic concentrations of mineral deposits.

The easternmost Omineca Belt, consisting predominantly of Paleozoic platformal sedimentary rocks with local to regionally significant younger intrusions, accommodates two concentrations of mineral deposits; from Cassiar north to the Yukon, and at Kutcho Creek nearly 100 kilometres east of Dease Lake. Principal commodities include asbestos, molybdenum, copper, zinc, lead, tungsten, gold, silver, jade, and placer gold. Access is achieved from Highway 37 for the Cassiar area deposits, and via a lengthy tote road from Dease Lake for the Kutcho Creek area.

The Intermontane Belt to the west consists of complex assemblages of volcanic, intrusive, and sedimentary rocks of various ages. Mineral deposits, concentrated in the Atlin,
Tulsequah, and Stikine-Iskut areas include copper, molybdenum, tin, tungsten, gold, silver, uranium and placer gold. Limited road and tidewater access is available to deposits in the Atlin and Tulsequah area respectively, other deposits are accessed by air.

The next most western tectonic regime, the Coast Crystalline Complex is comprised of young intrusive rocks and is not known to contain significant mineral deposits in the region.

The westernmost Insular Belt contains volcanic and sedimentary rocks of supposed Paleozoic age and Paleozoic to Tertiary intrusive rocks (MacIntyre, 1983). Only one deposit, the very significant Windy-Craggy copper-cobalt deposit, is known to date. Future exploration may discover additional deposits in this extremely remote and rugged area as the geology is better understood.

2.4.2 ECONOMIC POTENTIAL

The economic potential of mineral deposits located in northwestern B.C. is very substantial. Estimated gross value of the 26 well documented deposits in the thesis area exceeds $62.5 billion. Presently, four gold-silver mines and one asbestos mine are operative at Cassiar, a gold-silver-lead mine operates intermittently at Atlin, and a jade mine operates seasonally southeast of Dease Lake (Schroeter and Pan, 1982).

Table II lists these 7 mines and 19 undeveloped deposits. The table identifies each deposit's location, current
ownership, commodity type, grade, quantity, and estimated gross value based on mid-1984 metal prices. It is evident there is quite a range in deposit size and values owing to tremendous variability in commodity type and grade as a manifestation of the diverse geological environments. By aggregating the various deposits based on a modified mineral deposit size classification utilized in regional mineral evaluations in British Columbia (Northcote et al., 1983), it is possible to show that medium-size deposits ranging in value from $100 million to $1 billion comprise the largest category. Deposits in the very early stages of exploration are not included because value estimates of their reserves are very preliminary.

Aggregating total gross estimated values of each commodity as in Figure 3 permits a clearer definition of the primary determinants of potential widespread mineral development in the region. The profile reaffirms that copper and molybdenum will be the major determinants of future development in the region in the long-term as in previous studies (Ministry of Economic Development, 1977).

Tungsten and cobalt, however, while representing significant gross values, and contained in deposits with substantial molybdenum and copper respectively, face significant development constraints. The Windy-Craggy copper-cobalt deposit is situated in an extremely remote and hostile area, whereas the Logtung tungsten-molybdenum deposit requires substantial long-term improvement in metal prices.

Gold and silver are also significant factors that are
able to 'make or break' a feasible mining operation. These precious metals are pervasively associated with medium-size 'porphyry' copper and molybdenum deposits, vein-type, and placer deposits. Continued high prices for these precious metals will attract exploration investment and enhance the feasibility of known deposits.

The foregoing conclusions suggest a medium- to long-term mineral economy profile for the region based on specific commodities. It is emphasized, however, that fluctuations in the relative prices of metals will enhance potential profitability of deposits containing relatively higher priced metals at any one time. For example, over the last 5 years, higher prevailing prices for precious metals (gold, silver) coincident with depressed prices for base metals (copper, molybdenum, lead, zinc) has been reflected in exploration and development expenditures being directed towards comparatively high value to volume, small- to medium-sized deposits with important precious metal components. This has occurred even though total known base metal resources are substantially larger and anticipated to ultimately generate the greatest economic activity.
TABLE II. MINERAL DEPOSIT DATA

<table>
<thead>
<tr>
<th>DEPOSIT</th>
<th>OWNER</th>
<th>NTS LOCATION</th>
<th>COMMODITIES</th>
<th>RESERVES</th>
<th>GRADE</th>
<th>CONTAINED MATERIAL</th>
<th>ESTIMATED GROSS VALUE ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal Mines:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ATLIN SILVER</td>
<td>Trident Resources Inc.</td>
<td>104 N/12E</td>
<td>Ag, Pb, Zn</td>
<td>63,920 TN</td>
<td>527.31 gT Ag 5% Pb + Zn</td>
<td>33,705,655 g Ag</td>
<td>13,145,200 3,269,500 16,414,700</td>
</tr>
<tr>
<td>BAKER</td>
<td>Dupont of Canada</td>
<td>094/6E</td>
<td>Ag, Au</td>
<td>100,000 TN</td>
<td>28 gT Au 591 gT Ag</td>
<td>2,799,000 g Au 59,090,000 g Ag</td>
<td>40,501,530 23,045,100 63,546,630</td>
</tr>
<tr>
<td>ERICKSON</td>
<td>Erickson Gold Mining Corp.</td>
<td>104 P/4E</td>
<td>Au, Ag</td>
<td>65,000 TN</td>
<td>20.22 gT Au 20.22 gT Ag</td>
<td>1,313,975 g Au 1,313,975 g Ag</td>
<td>19,013,220 512,450 19,525,670</td>
</tr>
<tr>
<td>HANNA</td>
<td>United Bearne Res. Taurus Resources</td>
<td>104 P/5E</td>
<td>Au, Ag</td>
<td>440,000 TN</td>
<td>13.062 gT Au</td>
<td>5,747,280 g Au</td>
<td>83,163,140</td>
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<tr>
<td>VOLLAUG</td>
<td>Silver Standard Mines Ltd.; Cusac Industrisse</td>
<td>104 P/4E</td>
<td>Au, Ag</td>
<td>540,000 TN</td>
<td>15.55 gT Au 8.5 gT Au</td>
<td>8,397,000 g Au 4,590,000 g Ag</td>
<td>121,504,590 1,790,100 123,294,690</td>
</tr>
<tr>
<td>CASSIAR</td>
<td>Brisco Mining Ltd</td>
<td>104 P/SW</td>
<td>Asbestos</td>
<td>27,500,000 TN</td>
<td>38/ton @ 3%</td>
<td>15,876,000,000 kg 665,000,000</td>
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</tr>
<tr>
<td>CRY LAKE</td>
<td>Cry Lake Jade Mines Ltd.</td>
<td>104 I/3E</td>
<td>Jade</td>
<td>2500 TN</td>
<td>$0.5-$20/1b</td>
<td>n.a.</td>
<td>est. 10,000,000</td>
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<td>Undeveloped Deposits:</td>
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<tr>
<td>ADAMAC</td>
<td>Placer Development</td>
<td>104 N/11W</td>
<td>Mo, W</td>
<td>201,000,000 TN</td>
<td>0.96% MoSz</td>
<td>196,980,000 kg Mo</td>
<td>2,663,169,600</td>
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<tr>
<td>EAGLEHEAD</td>
<td>Essoi Nuspar Resources</td>
<td>104 1/6E</td>
<td>Cu, Mo, Ag, Au</td>
<td>&gt;30,000,000 TN</td>
<td>0.41% Cu 0.022% MoSz 2.71 gT Ag</td>
<td>123,000,000 kg Cu 3,780,000 kg Mo 61,300,000 g Ag</td>
<td>218,940,000 51,105,600 31,707,000 86,820,000 388,572,600</td>
</tr>
<tr>
<td>DEPOS.T</td>
<td>OWNER</td>
<td>NTS LOCATION</td>
<td>COMMODITIES(^1)</td>
<td>RESERVES(^2)</td>
<td>GRADE(^3)</td>
<td>CONTAINED MATERIAL</td>
<td>ESTIMATED(^4) GROSS VALUE ($)</td>
</tr>
<tr>
<td>---------------</td>
<td>-------------------------------</td>
<td>--------------</td>
<td>------------------------------------</td>
<td>-----------------</td>
<td>-------------</td>
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<tr>
<td>ERICKSON-ASHBY</td>
<td>Island Mining</td>
<td>104 E/11W</td>
<td>Ag, Pb, Zn, Au</td>
<td>1,000,000 TN</td>
<td>177.75 gT Ag 177,750,000 g Ag</td>
<td>69,322,500</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.7 gT Au 1,700,000 g Au</td>
<td>24,599,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.23% Pb 22,230,000 kg Pb</td>
<td>16,138,680</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.8% Zn 37,900,000 kg Zn</td>
<td>50,028,000</td>
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</tr>
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<td></td>
<td></td>
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<td></td>
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<td>160,088,480</td>
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</tr>
<tr>
<td>ONAT PASS</td>
<td>Hudson Bay Mining and Smelting</td>
<td>104 I/4</td>
<td>Cu, Au</td>
<td>20,030,000 TN</td>
<td>0.44% Cu 88,000,000 kg Cu</td>
<td>156,640,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.31 gT Au 6,200,000 g Au</td>
<td>89,704,000</td>
<td></td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>246,354,000</td>
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<tr>
<td>JOHN</td>
<td>Bella Mines</td>
<td>104 P/6W</td>
<td>Mo</td>
<td>11,793,600 TN</td>
<td>0.17% Mo, S 20,049,120 kg Mo</td>
<td>271,064,102</td>
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</tr>
<tr>
<td>KITCHIRO CREEK</td>
<td>Sumitomo; Ecco</td>
<td>104 I/1W</td>
<td>Cu, Ag, Zn</td>
<td>17,700,000 TN</td>
<td>1.5-2.3% Cu 313,740,000 kg Cu</td>
<td>557,976,600</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.3-2.4% Zn 523,620,000 kg Zn</td>
<td>691,178,400</td>
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<td></td>
<td></td>
<td></td>
<td>52-41% Ag 508,680,000 g Ag</td>
<td>198,365,520</td>
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<td>1,467,560,200</td>
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<tr>
<td>LAWYERS</td>
<td>Serem</td>
<td>094 E/6W</td>
<td>Au, Ag</td>
<td>735,000 TN</td>
<td>6.02 gT Au 4,424,700 g Au</td>
<td>65,043,100</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td>211.7 gT Ag 155,610,380 g Ag</td>
<td>60,688,000</td>
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<td>125,731,100</td>
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<tr>
<td>LEICHHAR</td>
<td>Brinco Ltd.</td>
<td>104 I/7</td>
<td>Asbestos</td>
<td>12,000,000 TN</td>
<td>$25 / TN 18,144,000,000 kg</td>
<td>500,000,000</td>
<td></td>
</tr>
<tr>
<td>LAGTUNG</td>
<td>Anax</td>
<td>104 O/13E</td>
<td>W, Mo</td>
<td>179,000,000</td>
<td>0.13% Mo 32,070,000 kg Mo</td>
<td>8,191,040</td>
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</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td>0.12% Mo, S 32,200,000 kg Mo</td>
<td>7,660,460</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>93,000,000 kg Mo</td>
<td>12,645,460</td>
<td></td>
</tr>
<tr>
<td>MIDWAY</td>
<td>Regional Resources</td>
<td>104 O/16</td>
<td>Pb, Zn, Ag</td>
<td>5,400,000 TN</td>
<td>323.5 gT Au 1,747,073,000 g Au</td>
<td>681,390,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Canamex Resources</td>
<td></td>
<td></td>
<td></td>
<td>12.3 gT Zn 200,000 kg Zn</td>
<td>453,601,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Procan Exploration</td>
<td></td>
<td></td>
<td></td>
<td>6.42% Pb 458,600,000 kg Pb</td>
<td>453,601,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>500,000,000</td>
<td></td>
</tr>
<tr>
<td>POLARIS-TAKU</td>
<td></td>
<td>104 E/12E</td>
<td>Au</td>
<td>95,964 TN</td>
<td>11.62 gT Au 1,115,101 g Au</td>
<td>16,135,511</td>
<td></td>
</tr>
<tr>
<td>RED-CHRIS</td>
<td>Kidd Creek Mines Ltd.</td>
<td>104 H/12W</td>
<td>Cu, Au</td>
<td>43,700,000 TN</td>
<td>0.56% Cu 244,720,000 kg Cu</td>
<td>435,601,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.28 gT Au 12,236,000 g Au</td>
<td>177,054,920</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>612,656,520</td>
<td></td>
</tr>
<tr>
<td>RED DOG</td>
<td>Northpits Mines Ltd.</td>
<td>104 G/9W</td>
<td>Au</td>
<td>2,200,000 TN</td>
<td>1.08 gT Au 2,376,000 g Au</td>
<td>34,380,700</td>
<td></td>
</tr>
<tr>
<td>SCHAF CREEK</td>
<td>Teck Corp.</td>
<td>104 G/7W</td>
<td>Cu, Mo, Ag</td>
<td>900,000,000 TN</td>
<td>0.3% Cu 300,000 kg Cu</td>
<td>5,341,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.03% Mo 300,000 kg Mo</td>
<td>5,341,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.12% Zn 992,000,000 kg Zn</td>
<td>5,341,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7.94 gT Ag 992,000,000 g Ag</td>
<td>386,800,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11,958,790</td>
<td></td>
</tr>
<tr>
<td>STRIKE</td>
<td>Liard Copper Mines</td>
<td>104 G/7W</td>
<td>Cu, Ag</td>
<td>125,000,000</td>
<td>1.06% Cu 1,325,000 kg Cu</td>
<td>2,358,500</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(GILFRED)</td>
<td></td>
<td></td>
<td></td>
<td>0.39% Cu 84,625,000 g Cu</td>
<td>718,073,50</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7.94 gT Ag 992,000,000 g Ag</td>
<td>387,075,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1,463,648,750</td>
<td></td>
</tr>
<tr>
<td>DEPOSIT</td>
<td>OWNER</td>
<td>NTS LOCATION</td>
<td>COMMODITIES¹</td>
<td>RESERVES²</td>
<td>GRADE³</td>
<td>CONTAINED MATERIAL</td>
<td>ESTIMATED⁴ GROSS VALUE ($)</td>
</tr>
<tr>
<td>------------------</td>
<td>-------------------</td>
<td>--------------</td>
<td>--------------</td>
<td>-----------</td>
<td>--------</td>
<td>--------------------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>STORIE</td>
<td>Shell</td>
<td>104 P/4W</td>
<td>Mo</td>
<td>100,000,000 TN</td>
<td>0.13% MoSz</td>
<td>130,000,000 kg</td>
<td>1,757,600,000</td>
</tr>
<tr>
<td>SUSITUF</td>
<td>Falconbridge</td>
<td>094 D/10E</td>
<td>Cu</td>
<td>30,000,000 TN</td>
<td>1.25% Cu</td>
<td>375,000,000 kg</td>
<td>667,500,000</td>
</tr>
<tr>
<td>TULSEQUAH</td>
<td>Cominco</td>
<td>104 K/12E</td>
<td>Ag,Au,Pb,Zn,Cu</td>
<td>714,874 TN</td>
<td>82.2 gT Ag 58,775,940 g Ag</td>
<td>22,922,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.6 gT Au 1,822,930 g Au</td>
<td>26,377,783</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.3% Cu 9,293,360 kg Cu</td>
<td>16,542,184</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.6% Pb 57,189,920 kg Pb</td>
<td>41,519,882</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.1% Cu 5,250,000,000 kg Cu</td>
<td>9,365,000,000</td>
<td></td>
</tr>
<tr>
<td>WINDY CRAGGY</td>
<td>Falconbridge; Geddes Resources</td>
<td>114 P/13E</td>
<td>Cu,Co,Au,Ag</td>
<td>350,000,000 TN</td>
<td>1.5% Cu 5,250,000,000 kg Cu</td>
<td>9,365,000,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.1% Co 350,000,000 kg Co</td>
<td>5,775,000,000</td>
<td></td>
</tr>
</tbody>
</table>

TOTAL ESTIMATED GROSS VALUE OF ALL DEPOSITS = $62,408,913,000

¹Ag - silver; Au - gold; Cu - copper; Co - Cobalt; Mo - Molybdenum; Pb - Lead; Zn - Zinc; W - Tungsten.
²Reserves - Metal mines - Proven and mineable.
- Undeveloped - Proven and drill indicated.
³Grade gT - grams/metric Tonne.
- kg - kilograms.
- lb - pound.
⁴Values - Prices used to compute values are approx. mid-1984 producer prices:
- silver - $0.39/gm; gold - $14.70 gm; copper - $1.78/kg; cobalt - $16.50/kg;
- molybdenum - $13.52/kg; lead - $0.73/kg; zinc - $1.32/kg; tungsten - $35.20/kg;
- asbestos depends on fiber quality.
⁵Raker Mine in the process of shutting down due to exhaustion of reserves.

Sources: Schroeter and Pan, 1982; Northern Miner Press Ltd., 1981-1985
2.4.3 CONSTRAINTS

The significant economic potential of northwestern mineral deposits has not been realized to date because of unsatisfactory combinations of factors required to encourage mining investment and maintain mining feasibility.

Constraints on development have been summarized in several previous studies (Ministry of Economic Development, 1977; Schroeter and Pan, 1982; Interministry Working Group on Northwest British Columbia, 1982; and Officials Committee on Northwest Economic Development, 1983).

A number of key constraints have been reported as common to all undeveloped deposits, although these will range in severity. The following constraints are especially important:

Metal prices - Prices for copper, molybdenum, lead, and tungsten in particular are presently depressed, reflecting general world economic conditions and existing inventory levels. This situation is beginning to show marginal signs for long-term reversal.

Transportation infrastructure - Nonexistent to substandard road access to most deposits would require major capital investment, and possibly amelioration of environmental consequences, to permit viable capital inflow and commodity outflow. Cost effectiveness of rail and slurry pipelines as alternatives is unclear.

Power - Lack of a regional scale industrial power source(s) and prohibitive distances to existing grid services dictate comparatively costlier, self-generation alternatives.

Environment - Large mines and their support
infrastructure, such as power generation and transmission facilities and communities will have uncertain consequences on terrestrial, aquatic, and amenity resources. Existing data bases make it difficult to estimate reliably the potential environmental impacts and mitigative alternatives.

Community infrastructure - Medium to large mines will require workforces ranging from 200 to greater than 500. Costs and options for housing require further study. The level of government involvement is uncertain.

Social impacts - Individual and cumulative impacts of mine development must recognize social priorities of existing residents. Native land claims are unsettled.

External impacts - Potential transboundary (B.C.-Yukon; B.C.-Alaska) impacts, primarily water resources, and to a lesser degree transportation, need identification in order to establish appropriate management strategies.

Government - Development policies and implementation strategies require refinement. Industry perceptions of government policy can either hinder or act as a beneficial catalyst.

Metallurgical - Bulk beneficiation studies and advanced metallurgical recovery techniques for mineralogically complex ores and lowgrade ores of certain commodities require further investigation for several deposits.

Other economic - Future cost trends of factors of production are difficult to predict. Likewise, political climate and tax laws can be significant determinants of project feasibility.
Figure 3. Total Estimated Gross Value of All Deposits

($Billions)
2.4.4  A SENSE OF DEVELOPMENT TIMING

Perhaps the greatest area of uncertainty regarding mining in the northwest is in the anticipated timing of development. This is the really important question for which there are few reliable answers. Forecasts of development are based on differing assumptions regarding trends and events pertaining to the primary factors determining a project's feasibility.

The Official's Committee on Northwest Economic Development (1982) has based its most recent timing forecasts on the attainment of the following pre-conditions:

i) An early and stable world economic recovery allowing investor confidence to develop;

ii) An early and sustained increase in base metal and industrial metal prices and export markets;

iii) Availability of the following infrastructure:

   - low-cost power supply,
   - improved and diversified highway system,
   - possible rail or commodity pipeline,
   - new or expanded ports,
   - strategically located communities; and

iv) Resolution of social, environmental and trans-boundary issues.

Preconditions are influenced in two ways: by external market forces and by government policies and actions. Strategic government involvement can therefore enhance development timing.

The B.C. government's recent attempt to gauge its
Figure 4: Copper Price Forecasts

*Actuals

Major U.S. Commodities Forecasting Group
Energy, Mines and Resources, Canada

Figure 5. Possible Production Schedule for Potential Medium and Large-scale Mines

Scenario 1 - Optimistic Price/Economic Outlook
alternative opportunities for involvement in northwest mineral development led to the formulation of two production schedule scenarios for the northwest based largely on anticipated metal prices for copper and molybdenum. The copper price forecasts used are shown in Figure 4, while Scenario 1, based on the optimistic price trend is shown in Figure 5. Scenario 2, the more pessimistic outlook, essentially defers development on average for 5 years.

Reassessment of the assumptions used to derive the government's anticipated production schedules suggests the likelihood of a somewhat altered future profile. First, the sustained increase in metal prices spanning 8-10 years, while possible, are improbable based on historical evidence (B.C. Ministry of Energy, Mines, and Petroleum Development, 1978; and Galway, 1974). As prices rise corresponding to world inventory reductions, a resumption of production from dormant mines along with new production from mines coming on stream will cause downward pressure on prices within perhaps 4 to 6 years. In addition, substitution effects such as those being experienced in the telecommunications industry, where fiber-optics are increasingly used, will exert downward pressure on copper demand and, therefore, prices.

Price corrections will result in a hiatus in projects coming on stream in the northwest until prices improve, possibly in the early to mid-1900's. A further important factor to consider is the volatile political influence of copper-producing developing countries, having a nationalized
industry. Developing country producers have caused distortions in supply/demand relationships during periods of rising prices, and exacerbated world-wide inventory stockpile reduction attempts during periods of declining prices (Western Miner, 1983). These activities tend to discourage investment in such traditionally higher cost mining areas as northern Canada.

Major mine development generally requires greater than 2 years of infrastructure construction prior to production. Assuming major government financing of infrastructure such as transportation and communities, as has been expressed in recent policy documents, then government will be required to deficit finance at least partially during the 1980's. The alternative is to delay government involvement pending pronounced improvement in the economy and general revenues. Government involvement is therefore anticipated to be step-wise in nature, relying initially on providing industry with incentives such as revised tax structures (for example, Parson, 1985), while gradually increasing expenditures in the transportation sector and perhaps eventually committing financing to community development if justified. The result will be that the largest mines requiring the most elaborate infrastructure will be further delayed. Small- to medium-sized mines with infrastructure capable of being capitalized by an individual corporation will be brought into production initially.

Based on the foregoing discussion, the following alternate scenario for mine development is anticipated:

i) Sustained increases in metal prices for copper,
molybdenum, zinc, and tungsten may catalyze development of comparatively richer and smaller projects with the least infrastructure requirements. These would include small-scale precious metal gold-silver deposits in the Toodoggone and Cassiar areas, and selective development of medium-sized base metal deposits such as Midway and Kutcho Creek, with the possibility of additional medium-sized porphyry copper-molybdenum deposits with significant precious metals, such as RED-CHRIS and Eaglehead.

ii) Progressive government involvement will occur in infrastructure creation, although this may become hindered by regional political and environmental uncertainties.

iii) A metal price plateau or period of declining prices is anticipated for the late 1980's or early 1990's, deferring development of large deposits (with possible exception of Schaft Creek) such as Adanac, Stikine Copper, and Windy-Craggy.

iv) Molybdenum deposits not into production by the late 1980's when U.S. Borax's Quartz Hill molybdenum deposit in southeastern Alaska is scheduled for production will be indefinitely postponed.

v) Overall, development is anticipated to occur as it has historically, on a piecemeal basis, in reaction to volatile metal markets, with a bias towards earlier development of comparatively higher value to volume, small- to medium-sized deposits requiring less capital investment, and containing an important precious metal (gold, silver) component.
2.5 ENERGY RESOURCES:

2.5.1 DISTRIBUTION AND DEVELOPMENT STATUS

Current power generation facilities in the northwest are comprised of multiple diesel generator units to serve local community and mining demands (Table III). Increases in demand are met by periodic installation of additional generating units. Future power supply options for the region include: hydroelectricity, thermal coal, geothermal, grid extension, and potentially biomass, wind, and natural gas. None of these are presently operable although the first three have been considered as alternatives to diesel generation for mine developments.

Diverse hydroelectric power opportunities, resulting from combined favourable topography and climate, range from 100 kW micro hydro sites identified for communities such as Eddontenajon, to the 2765 MW Stikine-Iskut and 3700 MW Yukon-Taku diversion megaprojects. Decisions to proceed with megaprojects will certainly have positive benefits for regional industrial development, however, their primary justification must come from provincial power planning. Micro and small hydro facilities are being increasingly considered as alternatives to costly diesel generation.

Coal deposits with thermal-electric potential are found in three locations. The first is the Groundhog coalfield located at the headwaters of the Skeena, Nass, and Spatsizi Rivers, straddling the proposed B.C.R. railway grade (Richards and Gilchrist, 1979). Mt. Klappan anthracite deposit, located at the northern end of this coalfield, contains an estimated 900 million
### TABLE III.

**Existing Diesel Power Generating Facilities**

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>OWNERSHIP</th>
<th>CAPACITY (kW)</th>
<th>END USE¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlin</td>
<td>B.C. Hydro</td>
<td>1750</td>
<td>C</td>
</tr>
<tr>
<td>Dease Lake</td>
<td>B.C. Hydro</td>
<td>1650</td>
<td>C</td>
</tr>
<tr>
<td>Eddontenajon</td>
<td>B.C. Hydro</td>
<td>800</td>
<td>C</td>
</tr>
<tr>
<td>Telegraph Creek</td>
<td>B.C. Hydro</td>
<td>1150</td>
<td>C</td>
</tr>
<tr>
<td>Stewart</td>
<td>B.C. Hydro</td>
<td>7250</td>
<td>C</td>
</tr>
<tr>
<td>Bob Quinn</td>
<td>Ministry of Trans-.</td>
<td>375</td>
<td>C/I</td>
</tr>
<tr>
<td></td>
<td>portation and Hwys</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Callison Ranch</td>
<td>Private</td>
<td>50 est.</td>
<td>R</td>
</tr>
<tr>
<td>Days Ranch</td>
<td>Private</td>
<td>50 est.</td>
<td>R</td>
</tr>
<tr>
<td>Inkin</td>
<td>Private</td>
<td>50 est.</td>
<td>R</td>
</tr>
<tr>
<td>McDame</td>
<td>Private</td>
<td>50 est.</td>
<td>R</td>
</tr>
<tr>
<td>Pitt Point</td>
<td>Private</td>
<td>50 est.</td>
<td>R</td>
</tr>
<tr>
<td>Pleasant Camp</td>
<td>Private</td>
<td>50 est.</td>
<td>R</td>
</tr>
<tr>
<td>Porter Landing</td>
<td>Private</td>
<td>50 est.</td>
<td>R</td>
</tr>
<tr>
<td>Scotia Bay</td>
<td>Private</td>
<td>50 est.</td>
<td>R</td>
</tr>
<tr>
<td>Sheslay</td>
<td>Private</td>
<td>50 est.</td>
<td>R</td>
</tr>
<tr>
<td>Surprise</td>
<td>Private</td>
<td>50 est.</td>
<td>R</td>
</tr>
<tr>
<td>Tahltan</td>
<td>Private</td>
<td>50 est.</td>
<td>R</td>
</tr>
<tr>
<td>Taku</td>
<td>Private</td>
<td>50 est.</td>
<td>R</td>
</tr>
<tr>
<td>Tatogga Lake</td>
<td>Private</td>
<td>25 est.</td>
<td>R</td>
</tr>
<tr>
<td>Tulsequah</td>
<td>Private</td>
<td>50 est.</td>
<td>R</td>
</tr>
<tr>
<td>Warm Bay</td>
<td>Private</td>
<td>50 est.</td>
<td>R/I</td>
</tr>
<tr>
<td>Erickson Gold Mine</td>
<td></td>
<td>990</td>
<td>M</td>
</tr>
<tr>
<td>Hanna Gold Mine</td>
<td></td>
<td>800 est.</td>
<td>M</td>
</tr>
<tr>
<td>Vollaug Gold Mine</td>
<td></td>
<td>800 est.</td>
<td>M</td>
</tr>
<tr>
<td>Baker Gold Mine</td>
<td></td>
<td>750 est.</td>
<td>C/M</td>
</tr>
<tr>
<td>Cassiar</td>
<td></td>
<td>19,000</td>
<td>C/M</td>
</tr>
<tr>
<td>Cry Lake Jade</td>
<td></td>
<td>100 est.</td>
<td>M</td>
</tr>
</tbody>
</table>

³End Categories: C - Community; I - Industrial; R - Residential, Resort and Seasonal Industrial; M - Mining.

tonnes of drill indicated and inferred reserves. Mt. Klappan is under investigation by Gulf Canada Resources for its export potential and a production decision is anticipated for 1985 (Western Miner, 1984a; ibid, 1984b). The deposit's proximity to northwest metallic mineral deposits suggests potential for onsite power generation and regional transmission. The second area of coal deposits is in the Tuya-Tahltan River area between Telegraph Creek and Dease Lake. Extensive further exploration is required to assess the appropriateness of this poor quality lignite coal for power generation. Lignitic coal deposits also occur sporadically over a 50 square kilometre northwest-trending basin which straddles the Rapid River east of Cassiar. Few coal quality data are available (Dolmage, Campbell, and Associates, 1975).

Geothermal energy potential adjacent to the Recent Mt. Edziza volcanic pile is under current investigation by Energy, Mines, and Resources of Canada (Western Miner, 1983; Jessop et al, 1984). Proximity to the Schaft Creek copper-molybdenum deposit and Red Dog gold deposit suggest electrical generation or space heating applications may be areas for further investigation. However, as investigations are preliminary, estimates of the size and quality of this resource are premature.

B.C. Hydro has investigated the costs of extending existing grid service northwards to serve local mines in the Stikine area. A 230 kV to 287 kV line from Telkwa or Skeena substations would cost on the order of $100-140 million (1982)
and require 7 years from design through approval and construction to completion (Interministry Working Group on Northwest British Columbia, 1982). The cost of this option is considered prohibitive at this time.

A further possibility is grid extension to the Atlin or Cassiar area from the Yukon should one or more proposed hydroelectric facilities to serve mining, aluminum smelting, or pipeline electrification proceed. This possibility seems remote at present.

Extensive non-commercial forests in the northwest may provide a fuel source for power generation for small demand centres. This renewable energy source along with others, such as wind and solar, have yet to be investigated for their potential contribution to northern power supply.

2.5.2 DEVELOPMENT STIMULI

Growth in regional energy demand is predicated on activity in two principal sectors: community expansion and mining development including support infrastructure. Provincial energy demand growth will further B.C. Hydro's efforts to continue investigation of megaprojects such as the Stikine-Iskut, which may have important implications for initiating regional demand through the availability of potentially low-cost power.

Increased power demands resulting from expansion of existing communities is anticipated to continue to be met by additional diesel generator installation with possible limited
substitution of micro hydro.

Mine developments will continue to be the principal industrial source of power demand. Small precious metal mines will continue to rely primarily on diesel because of turnkey convenience and short duration of these mining operations. Micro and small hydro projects may increasingly supply base load or substitute for diesel when a suitable site is located within economic transmission distance.

Medium- and large-sized mines will result in the most profound growth in regional energy demand in the foreseeable future. The location and timing of these projects, as determined by the progressive removal of development constraints previously outlined, will determine the nature of energy supply options and whether projects are developed singularly or on a shared basis.

Increased activity in the forest sector, although difficult to forecast, will result in a lower level of new power demands than mining.

2.5.3 **POWER SUPPLY REQUIREMENTS FOR MINING**

Metal mines and mineral processing facilities are energy intensive operations. Specifically, with large tonnage, low-grade copper-molybdenum deposits such as those prevalent in the study area, energy consumption in the extraction and milling process could become the most important factor in deciding mine feasibility (Joe, 1979). For example, the Mining Association of British Columbia's annual survey of producing
mines in British Columbia determined that total energy costs of production now exceed 13% of total production costs and are among the fastest rising cost factors of production. The Schaft Creek copper-molybdenum deposit, the largest deposit in the region, for example, would require nearly 80 MW installed capacity for mine, mill, and townsite. Capital cost of power supply and distribution are estimated to be 22% of total project capital costs (Ministry of Energy, Mines, and Petroleum Resources, 1983). Table IV lists the anticipated power supply requirements for several other potential mines in the region. Comparing these data with Table III, it is evident that power requirements for one or more mines could substantially overshadow total existing installed capacity in the region.

Understanding the possible timing of various mineral deposits would permit strategic planning of power generation facilities to take advantage of economies of scale and optimize transmission distances, thereby reducing the cost of power and enhancing mine feasibility. Power generating facilities large enough to serve several mines, however, will require greater lead times for design, application, and construction. Indeed the sole justification for these projects would be to supply power to potential mines and so firm commitments would have to be made by mining companies in advance.

Unfortunately, the anticipated timing of mineral development during the latter 1980's and early 1990's is subject to considerable uncertainty as a result of unsettled metal prices and other development-related constraints alluded
to earlier. Faced with this situation, owners of small- to medium-sized deposits, given metal prices sufficiently encouraging to decide on production, will have one of two power generation alternatives to choose from: pursue self-generation of a least cost alternative, or defer production until a larger low-cost power source is developed among several producers or through government involvement.

The foregoing uncertain relationships between future regional power generation and mineral development timing led to the present study's desire to investigate alternate forms of power generation for medium-sized deposits and in particular to establish a methodology at the reconnaissance level capable of evaluating and selecting the most preferred alternatives.

TABLE IV.

<table>
<thead>
<tr>
<th>DEPOSIT</th>
<th>EST. INSTALLED CAPACITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kutcho Creek</td>
<td>3.5 - 13 MW</td>
</tr>
<tr>
<td>Letain</td>
<td>8.5 - 15 MW</td>
</tr>
<tr>
<td>Stikine Copper</td>
<td>48 - 55 MW</td>
</tr>
<tr>
<td>Shaft Creek</td>
<td>80 MW</td>
</tr>
<tr>
<td>Adanac</td>
<td>13 MW</td>
</tr>
<tr>
<td>Red-Chris</td>
<td>4.5 - 15 MW</td>
</tr>
<tr>
<td>Sustut</td>
<td>10 - 30 MW</td>
</tr>
</tbody>
</table>

2.6 CONCLUSIONS

This chapter has presented a synopsis of the primary resource sectors of the 150,000 km$^2$ study area encompassing northwestern-most B.C. The region contains a diversity of forest, wildlife, fisheries, mineral, energy, and recreational-amenity resources. While there is common acknowledgement that these resources are at the same time abundant and underutilized, a paucity of comprehensive substantive data, with the exception of minerals, has inhibited comparison and analysis of future management options.

Public preferences regarding the use, allocation, and management of these resources range from those who desire a cautious, environmentally sound, slow pace of economic development in order to preserve a quality wilderness lifestyle and give time to resolution of aboriginal land claims, to those who view an enhanced pace of economic development primarily through diversified mining, forestry, and energy activities as providing the cornerstone for future regional prosperity and stability.

Mineral resource development is gaining momentum as the region's major economic resource activity for the foreseeable future. However, constraints associated with transportation, power, metal prices, and environmental uncertainties will have to diminish in order to realize production of metals from current reserves estimated to exceed $46 billion in value.

The remote setting of existing and potential mines has underlined the need to further investigate power supply options
Presently, the lack of a regional power source and prohibitive distances to existing public utility transmission networks dictate self-generation alternatives. These are perceived to be costlier.

Given the foregoing situation in combination with the uncertainty of timing for individual mineral developments, it is concluded that the next step in investigation from a public planning perspective lies in the development of a strategic analytical framework that can be applied to the assessment of power generation alternatives for individual mines. To add relevance to this task, the framework will need to focus on potential mines whose power requirements fall short of the regulated standards imposed by the B.C. Utilities Commission Act yet have sufficient duration to justify consideration of other than diesel powered generation.

The remainder of this study develops this theme in three stages. First, a general review is conducted of the evaluation literature, followed by a focused review of evaluation techniques with specific application to the problem. The essential elements identified in the theory represent the basis for developing subsequent chapters. Secondly, a reconnaissance level methodology is proposed for evaluating power supply options for uncertain mineral development futures. Finally, the power requirements of an 'average' mineral deposit, RED-CHRIS, are investigated and power supply options selected, through an application of the proposed methodology.
CHAPTER THREE
THEORY AND PRINCIPLES OF EVALUATION

3.1 PURPOSE AND INTRODUCTION

The principal intent of this chapter is to outline concepts in evaluation theory and to describe techniques commonly used by public and corporate interests to carry out energy project evaluation.

The first part of the chapter reviews the literature on evaluation theory, and outlines the basic elements of normative evaluation which form the basis for specific decision-making approaches.

The second part of the chapter distinguishes between corporate and various public (governmental) decision-making perspectives by describing how they are reflected and emphasized in different energy project evaluation approaches. For example, since it is the mandate of the government to consider multiple objectives, and therefore trade-offs between equity and efficiency, and multiple participants, such as native groups and non-residents, the governmental approach to project evaluation is designed to address broad social perspectives. In comparison, corporate decision-making mandates are much more narrowly focused on attaining economic profits within certain minimum social constraints, and therefore the energy project evaluation approach is comparatively simplified. It is important to understand this distinction because it determines the manner in which the issues identified in the preceding chapter are resolved in terms of choosing between alternative energy projects.
This chapter therefore links the issues identified for the problem environment introduced in Chapter 2, together with theoretical and practical evaluation procedures, to the development and application of an energy project evaluation methodology proposed in subsequent chapters.

3.2 OVERVIEW OF EVALUATION THEORY

3.2.1 Evaluation Techniques

The central purpose of evaluation is to help individuals judge the desirability of proposed actions based on an organized analysis of the best available information pertaining to costs, benefits and risks, whether quantifiable or not. An easily understood evaluation methodology founded on clearly enunciated principles therefore provides the cornerstone of a well orchestrated decision-making process.

A great variety of evaluation techniques have been formulated for use in normative decision-making processes. All share in common a number of attributes. The framework outlined below combines the five common basic elements as outlined in McAllister (1980) and Quade (1982).

1. Identify or formulate the problem and clarify objectives.
2. Design alternate solutions by examining data and relationships.
3. Evaluate alternatives.
4. Recommend or decide on action(s) for implementation.
5. Monitor the results and where possible verify conclusions.
In practice, moving from step 1 through 5 is seldom a straightforward process. Instead there are usually complete or partial iterations as new information, modified objectives, alternatives and evaluation techniques evolve over time, and as uncertainty is increasingly managed. Figure 7 illustrates this aspect.

A review of the literature for normative concepts pertaining to each step is presented in the following sections. Uncertainty, as a feature that pervades the entire decision-making process, is examined separately.

Figure 7. Iteration in the Decision-Making Process from Quade (1982)
3.2.1.A. Problem Formulation and Objective Clarification

Formulating the problem involves first, an intuitive recognition that a problem exists, and secondly, defining parameters or constraints in response to an explicit set of policy assumptions within which the problem is bounded. It will be useful to know what, if any, prior decisions have been made and how they have been manifest in determining constraints on the current problem. A clear understanding and consensus on assumptions, among participating interests in the process, is vital to formulating objectives.

Determination of what objectives are, or should be, is often the most difficult task faced by the analyst (Quade, 1982). Keeney and Raiffa (1976) have conceptualized the problem of clarifying objectives corresponding to vector attributes existing at a high level within the hierarchy which are composites of lower level scalar attributes corresponding to lower level objectives.

Objectives can be generated by a variety of means. MacCrimmon (1969) suggests examination of the relevant literature, analytical study and casual empiricism. Keeney and Raiffa (1976) additionally suggest surveys and expert group choice. Katz (1971) concluded that ambiguous objectives or objectives poorly related to the problem area can be refined by determining the interests of those enterprises initiating a decision-making process, as well as identifying affected secondary parties drawn into the process. Where multiple competing interests hinder objective clarification, concepts
such as value sensitivity analysis proposed by Nash, Pearce and Stanley (1973) are useful for anticipating evaluation outcomes in response to alternative value sets.

Value preferences of participants in the decision-making process must be explicitly recognized when identifying objectives; for as Lindblom (1959) has succinctly stated, "Social objectives do not always have the same relative values." Keeney and Raiffa's (1976) approach to dealing with differing value preferences has been to develop more than one hierarchy of objectives corresponding to each value set in order to elucidate trade-offs that might otherwise not be recognized. This technique implicitly acknowledges that attaining certain objectives will require trade-offs with others.

Resource use preferences identified in the present study range from environmentally sensitive slow-pace development to accelerated industrial development. This range of preferences exemplifies a decision environment with complex interactions. Because of considerable uncertainty in the nature of energy resource availability to mining, it is anticipated that more precise definition of the problem environment, and the implied consequences of solutions, will permit the initial objectives of interest groups to become progressively refined and modified. Value preferences of all groups will need to be flexible to accommodate these changes.
3.2.1.B. Design of Alternatives

Alternatives are the choices or options available to the decision-maker by which he hopes to attain his objectives and improve his particular situation (Quade, 1982; Mack, 1971). Consideration of the broadest possible number of alternatives is generally desirable at the onset of evaluation so that potentially desirable ones are not excluded later in the process (Lichfield, Kettle and Whitbread, 1975). The status-quo, no-action, and newly invented alternatives should all be considered as contenders in the first instance. Because of the iterative nature of analyses, leading to possible redefined problems and objectives, analysts cannot be bound to an immutable set of alternatives, but rather must continually appraise their validity.

Where an initial list of alternatives is large, these may be pre-screened on the basis of feasibility, efficiency, political desirability, or other prime criteria, to achieve a manageable number. The remaining alternatives would then represent the most likely candidates for eventual selection; however, opportunities must be available during successive iterations of the evaluation process to reinstate earlier discarded alternatives or accommodate new ones as supportive information becomes apparent or objectives are potentially modified. (Keeney and Raiffa, 1976; Mack, 1971).
3.2.1.C. Evaluation of Alternatives

Evaluation of alternatives concerns that part of the decision-making process where the attributes or decision criteria values are critically examined in order to determine which alternatives best attain the objectives. At the end of the evaluation stage, a long list of alternatives will have been narrowed, by virtue of rating costs, benefits, and other consequences, to those few that either merit a more detailed look or can now be forwarded for decision.

McAllister (1980) has reasoned that the evaluation stage must be carried out in a strategic manner to focus attention on those factors judged most capable of critically distinguishing among alternatives. Impacts and attributes that are relatively invariant among alternatives can be assigned a low priority or ignored.

Hickling (1975) has subdivided the process into two interconnected steps, valuation and evaluation. Valuation involves understanding for each alternative, their data relationships to a specified set of functional parameters or attributes. An integral part of valuation is the establishment of criteria, the means of measurement, which allow the analyst to keep track of differences between alternate choices in terms of their effects. Evaluation attempts to rank the alternatives as to desirability on the basis of the valuation(s). There are several sub-steps to be undertaken and a variety of factors to consider during both valuation and evaluation.

1) Valuation - Hickling (1975) has identified three
aspects of valuation pertaining to the consequences of alternatives by which they may be compared: the range of effects, meaning which effects should be considered and who is affected; the scale of effects, in particular how much of each kind of effect is apparent and the nature of distributional effects; and finally the value of effects, in other words the utility or trade-offs experienced.

Hickling's typology of criteria can be reinforced by incorporating the following operational properties identified by Keeney and Raiffa (1976) for each aspect of the typology. The desirable properties are: completeness in order to adequately cover the important aspects of the problem; operational implying meaningfulness so that alternative implications are evident; decomposable, so that aspects of the evaluation process can be disaggregated; nonredundancy, to avoid double-counting of consequences; and minimum size, so that the problem dimension is constrained to examining critical trade-offs.

Workers in the field of environmental analysis have used the concept of indicators, "measures of system behaviour in terms of meaningful and perceptible attributes" (Holling, 1978) to fulfill the analogous role of criteria. Indicators can be classified according to economic, ecological or social affinities.

ii) Evaluation - Evaluation is a complex process involving quantitative comparison, value judgement, and intuitive reckoning. During this stage, referred to as
"post-design" by McAllister (1980), criteria may be aggregated, weighed, assigned ratings and compared. Where the decision environment is characterized by a few criteria, evaluation can be straightforward. More commonly, decision environments involve multiple objectives and are characterized by multiple criteria. Specialized techniques developed to deal with these complex situations include simple step-wise selection based on dominance, satisficing (meeting minimum criteria), and abstract mathematical non-metric scaling procedures (MacCrimmon, 1968). Most of these techniques have a statistical or economic bias and their underlying premise rests on the assumption that choice will be carried out by rational man.

iii) Method - Cost-benefit analysis (CBA), cost-effectiveness analysis (CEA), goals-achievement matrix (GAM), planning balance sheet (PBS), environmental evaluation system (EES), and planning, programming budgeting system (PPBS), represent the more common techniques that are well documented in the literature (Canada Treasury Board Secretariat, 1976); McAllister, 1980; Rivlin, 1972; McLoughlin, 1969; Weiss, 1972; Hill, 1968). Gilliland (1975) and Bowles (1981) discuss techniques such as net energy analysis and social impact assessment which are especially important to energy project evaluation.

These techniques, although widely used, have also been extensively critiqued. In some instances their value has been judged as equivocal (Williams, 1972). In fact there appears to be general consensus in the literature, despite widespread
usage of the techniques, that their primary value is in
guidance of the selection process rather than as means by which
choices are determined (McLoughlin, 1969).

For example, regarding cost-benefit analysis, Mishan
(1974) cautions against the use of CBA with politically set
prices to guide social policy for the reason it may be
impossible to present a clear interpretation of results or
support them because of obvious inadequacies in the technique's
ability to consider distributional effects and equity. Thus he
reasons that CBA can only be a part of evaluation. As Nemetz
et al (1979) so cogently remind us:

The question is not whether quantitative analysis is
better, but what are the safeguards to ensure
meaningful measurement and integration of quantitative
analysis into a political, informed choice process.
The quantitative decision process should be used only
to screen options and provide information about
trade-offs. . . . Whatever specific technique is
chosen, its main role is to focus the
intuitive-political choice process by presenting
reasonable options which meet certain formal demands as
well as presenting some additional information about
the interrelationship of these options and the
constraints. (p. 275)

3.2.1.D. Interpretation, Decision, and Implementation

i) Deciding to Decide – Making a decision requires
consideration of several ways to achieve a desired result.
Decisions are based on a coalescence, interpretation and
judgement of information currently at hand regarding good and
bad consequences of an alternative course of action. A
reassessment of assumptions and an understanding of value
preference structures are most important. With such a
multitude of considerations, it is not surprising then, that
decision-making, deciding how to decide, can be the most
complex stage in the process.

Hickling (1975) has mapped three possible routes that a
decision can take: an action route wherein decisions to carry
out certain actions are immediately acted on, including
gathering further information prior to implementation; a
contingency route wherein a specified procedure will take place
when certain events occur, or constraints will be imposed on
possible outcomes; and a delayed action route wherein solutions
to foreseeable problems are specified but these are provisional
or conditional in some way, with specification of the nature of
foreseeable problems, possible timing, and dependent
conditions.

ii) Decision Factors – Several authors have suggested
guidelines to assist the decision maker. For example, Rivlin
(1972) reviewed four factors to consider from the perspective
that decisions ultimately involve choices among alternative
uses of scarce resources. Firstly, decision makers are urged
to be explicit about what alternative resource allocations are
being considered, by means of attaching quantitative dimensions
to criteria. Secondly, decisions will be improved if
trade-offs are made explicit. Thirdly, the dimensions or
vector attributes must be clearly specified for alternatives
capable of attaining the same objective. Finally, Rivlin
cautions for the need to trace distributional effects as a
means for distinguishing among alternatives.
Four additional factors not discussed by Rivlin (1972) are also important for decision makers. Value trade-offs and preferences are investigated in a lengthy work by Keeney and Raiffa (1976) in which they indicate that the nature of preferences and procedures by which the consequences, distributional effects and other attributes of particular alternatives become aggregated can significantly alter the course of decision making. The writers point out the importance of assessing preference structures, essentially a hierarchy of values attachable to the decision maker and his constituents, explicitly including interpersonal comparison of preferences. The first hierarchy of preferences would be expected to correspond closely with high level objectives and attributes as previously discussed under objectives. Similarly, lower hierarchy preferences would coincide with low-level attributes.

iii) Value Preferences - Value preferences are often closely related to perceptions of equity. The concept of equity concerns the distribution of costs and benefits among members of society (McAllister, 1980). Equity objectives must be explicitly faced and considered along side economic efficiency criteria if consequences relating to alternatives are to be truly represented in the decision-making process (Leman and Nelson, 1981; Clawson, 1980).

iv) Externalities - Externality implications of multi-objective, multi-attribute problems can become important if the decision environment embraces a regional perspective.
Russell (1982) defines externality as:

... [applying] generally to situations in which firm (or individual) A creates through its activities a cost or a benefit for firm (or individual) B but does not take this cost or benefit into account in making its decisions about its own production or consumption.

Russell recognizes three kinds of externality:

- **Pecuniary externalities** (which) involve market interactions;
- **Real externalities** (which) involve direct interactions through competition for a common property resource; and
- **Political externalities** (which apply to) situations in which the design (constitution) of our political institutions creates conflicts by excluding from collective decisions the voices of legitimately interested parties, and to situations in which the decisions or actions themselves prevent the resolution of conflicts arising from another type of externality.

Dealing effectively with externality involves consideration of equity over various time horizons, assessment of value preferences over time, and a willingness to adapt decisions to smooth out short-term consequences while maintaining longer term objectives.

v) Uncertainty – Since the future is always uncertain, evaluations can never really be predictive and hence the outcome of decisions can never really be certain (Holling, 1978). Uncertainty pervades the entire decision-making process. Uncertainty concerns factors that are not predictable and that affect the success of a course of action (Quade, 1982). While uncertainty cannot be removed, it certainly can be interpreted, classified, and even managed for.

The literature is replete with studies examining uncertainty in the context of decision analysis (Holling, 1978; Hickling 1975; Quade (1982). Uncertainty and a related theme,
risk, will be discussed in greater detail in Section 3.2.2.

In summary, the process of making a decision, or deciding to decide, is a complex task. It requires a high standard of interpretation and judgement of multiple attributes and consequences of competing alternatives. In practice, limitations on resources available to the decision makers and analyst often result in incomplete data, unspecified assumptions, conflicting value preferences and a host of other problems, all adding further uncertainty. Inevitably, the decision maker must apply his best judgement to the most explicitly stated available mix of intuitive, political and analytical factors.

3.2.1.E. Monitoring and Verification

Once a decision has been implemented, the affected parties may wish to verify the consequences. This can be accomplished by comparison with previously collected baseline information, by experimental simulation, or by investigative activities of outside professional analysts. Problems that require a sequence of decisions and implementation phases may incorporate future monitoring and verification information into the evaluative process preceding subsequent decisions.

In situations of considerable uncertainty, a continuing cycle of monitoring, assessment and adapting future decisions to new information will occur. The evaluation stage of decisionmaking will, in such situations, become indistinguishable from ongoing management.
3.2.2. UNCERTAINTY

3.2.2.A. Definition

Uncertainty was introduced in the preceding section as an integral part of decision-making processes. Uncertainty arises because of deficits in knowledge required to produce correct decisions. Therefore, uncertainty can be defined as "the unpredictabilities in factors that affect the success of a course of action" (Quade, 1982).

Uncertainty is important to the decision maker primarily because it cannot be eliminated, and therefore is difficult to design for, in decisions that have implications for the future. Mack (1971) has reasoned that the level of uncertainty directly affects the aspiration level of a decision—that level of finesse appropriate to a decision, since a high level of uncertainty reduces available choices.

Uncertainty should not be ignored in the hope that it will be inconsequential. The only logical tact therefore is to accommodate uncertainty by analyzing its sources, classifying its types, and devising management approaches to incorporate it into the various stages of evaluation and decision-making.

3.2.2.B. Uncertainty vs. Risk

At this point it will be useful to distinguish uncertainty from risk, as they are often confused or used interchangeably. Risks are traditionally defined as "stochastic uncertainties whose probability distributions are
known" (Quade, 1982). Recent workers in the growing field of risk-benefit analysis have expanded this definition to include societal perceptions of risk. Thus risk can be considered as a product of the probability of an event occurring, and the perceived severity of each event (Wilson and Crouch, 1982). Like uncertainty, risks cannot be eliminated. The objective of assessing risks therefore, is to minimize the potential occurrence of negative consequences of decisions.

Understanding of ways to reduce risk can be accomplished by rigorous analysis and extrapolation of historical data where the classes of risk are well known, and by historical analogy and model development where risks have no historical precedent (Wilson and Crouch, 1982).

The common causes of uncertainty in risk analysis are incomplete or inaccurate raw data, ignorance about causes and effect, and value judgements on risk and equity (Ramsay, 1981).

3.2.2.C. Kinds of Uncertainty

Uncertainty can be classified into three kinds based on the respective sources (Hickling, 1975). The first of these is uncertainty in the operating environment, resulting from inadequacies in information to be used for quantitative or qualitative comparison. The second is uncertainty about policy values resulting from unclear, unspecified or conflicting objectives. The objective hierarchy approach discussed in detail by Keeney and Raiffa (1976), which was introduced in the preceding section, is specifically aimed at reducing this kind
of uncertainty. The final kind of uncertainty concerns choices in related areas of decision. This arises from the obvious need to constrain a problem area at the expense of not explicitly including interrelated areas and future decisions outside the decision environment that may alter the consequences or aspiration level of the decisions at hand.

3.2.2.D. Dealing With Uncertainty

Since uncertainty cannot be ignored, there are two methods of dealing with it; one way is to accept and resolve it through a variety of management approaches. The second method is to reduce it by formulating a scheme or contingency plan that makes uncertainty inconsequential (Hickling, 1975; Quade, 1982).

If uncertainty is accepted, techniques such as risk analysis, surprise limits analysis, and the Bayesian approach to decision analysis (analysis of judgemental probabilities) can be utilized to help understand the relationships of uncertainty to the decision problem. Ideally, solutions will exhibit traits of adaptiveness: the ability to change and keep options open; and, robustness, the lack of sensitivity to outside influence (Hickling, 1975). Since institutions and individuals can only live successfully with uncertainty by maintaining an ability to respond to change, management techniques must be capable of improvement through experiencing uncertainty (Holling, 1978).

If efforts to deal with uncertainty are directed at
attempts to reduce it, the three kinds of uncertainty outlined above must be examined in detail by establishing a hierarchy of disaggregated component parts. Techniques such as cost-effectiveness and sensitivity analysis can then be applied. A checklist such as that outlined by Mack (1971) can be a useful procedure for itemizing the types of uncertainty to be reduced.

Whatever technique is chosen, the primary benefit will lie in conveying a better understanding of uncertainty such that better decisions are approachable.

3.3. **MULTIPLE OBJECTIVES AND EVALUATION DESIGN**

3.3.1. Interest Group Perspectives and Approaches to Energy Project Evaluation

In any multiple-interest decision-making environment, there must be an explicit recognition of the major interest groups represented, and their principal objectives. This provides information for the analyst about the scope of values that influence decision-making. However, since it is generally impossible to optimize major interest group objectives simultaneously, as Keeney and Raiffa (1976), and Quade (1982) have pointed out, a logical approach is to identify key objective functions for which it is possible to provide critical information in areas of greatest uncertainty to help distinguish between alternatives (McAllister, 1980).

Typically, for energy resource allocation issues, a
multitude of societal and private preferences and objectives are discernible. For example, social objectives will routinely internalize questions of equity and distribution such as those related to environmental costs, as part of economic efficiency, while private objectives of a resource corporation will be concerned with these questions only as external constraints on maximization of investment return. It follows therefore, that the information needs of groups will differ, and so too will the corresponding analytical techniques used to measure the effectiveness of alternate decisions against objectives.

Energy project evaluations have attained widespread prominence in society during the last decade as heightened awareness of energy's role in the functioning of economies emerged following the Arab oil embargo of 1973. The resolution of energy problems, whether of individual or national scale, must now be considered in relation to the constraints, influences, and value trade-offs of complexly intertwined economic, social, environmental and political systems (Eden et al., 1981). In British Columbia, the Utilities Commission Act's Energy Project Review Process is an example where comprehensive analysis of a project is brought into the political arena when large producers or consumers of energy are involved.

Energy supply issues for economic development in northwestern B.C. contain elements of all the foregoing. Evaluating energy supply options available to mining thus involves consideration of a variety of objectives and the trade-offs they imply. Resource use preferences of corporate,
government, native and diverse resident and non-resident citizen groups identified in Section 2.3 provide the present framework within which objectives and trade-offs will be investigated.

At the preliminary evaluation level examined herein, effective representation of the variety of objectives determined for each preference group is best achieved by concentrating on areas of critical information, and identifying the respective key evaluative criteria for energy project appraisal corresponding to these preference groups.

For practical purposes, objectives can be combined into a number of groups to which it is possible to assign specific evaluation approaches. Each evaluation approach represents a specialized application of decisionmaking elements introduced in the first part of this chapter.

The following four-part classification based on generalized interest group objectives is proposed.

1) Mining Corporations - This group reflects the resource development end member of the range of resource use preferences. For the present problem area it is represented by a mining company perspective. The principal objective of a corporation engaged in the mining industry is to create investments that provide a positive return to shareholders equity. Energy supply is but one cost factor of a mining endeavour. Mining corporations will be concerned primarily with criteria related to project feasibility from a standard technical and business aspect. This is commonly referred to as
an engineering evaluation.

2) Societal Interests — This group reflects a broad range of societal preferences. It differs from Group 1 by a broader inclusion of human and environmental welfare concerns into the process of energy project evaluation. Specifically included are native and non-native northern residents whose lives and environment are apt to be transformed by electrical generation projects. They will be vitally concerned with assessing the benefits/costs, timing and scale of such transformations. A traditional social/benefit cost analytical framework will thus be examined as an energy project evaluation technique for these social concerns.

3) Public Energy Policy Interests — A collective desire by society to maintain a high quality of life has manifested itself in public policies concerned with energy futures. Although energy projects of the scale covered by this study are insignificant from a provincial and national perspective, their cumulative effect urges assessment in relation to broader provincial or national energy policy. A conceptual basis for energy policy is introduced and key objectives and evaluative criteria identified. Objectives and criteria are important to a wide range of resource use interests both within and outside the region. This objective set can be regarded as a specialized subset of (2).

4) Institutional Interests — This group represents resource use preferences related to government and other institutional objectives. They overlap many of (1), (2), and
(3) above, but are additionally manifested in legal, regulatory, and financial constraints and requirements. These are important as they represent costs to the proponent and safeguards to society which influence the attainment of their respective objectives. This aspect of energy project evaluation is reviewed primarily from the perspective of the project developer in terms of constraints on the project which are likely to be experienced. Once again, institutional objectives are really a specialized subset of (2).

Groups 1 to 4 are reviewed in the following sections. One aspect to be noted, is that while there are obvious overlaps in techniques and criteria of evaluation, the discussions have adopted a somewhat narrowed view for each objective set. The reason for this is to heighten the real and apparent dissimilarities. Thus for example, while both engineering project analysis and social/benefit cost analysis utilize forms of benefit/cost analysis derived from the same basic concepts, the way in which the technique is applied differs as a result of contrasting objectives and values of the private firm and governments.

3.3.1.A. Engineering Evaluation
i) Introduction to Technique

A mining company engaged in the development of a mineral deposit is concerned with the evaluation of numerous components, including mining, milling, transportation, housing,
and energy supply. The purpose of this section is to relate the corporate approach to evaluation of the energy supply component.

The standard engineering approach to energy project investment has as its prime objective that of producing maximum output of electric power of optimum quality by the most economically feasible method within predetermined design parameters. Ossenbruggen (1984) outlines three important investment factors to consider:

First, the selection process is competitive, and not all opportunities are worthy of investment. Second, there are risks that must be considered. Third, the anticipated earnings or benefits are not received at the time of the exchange of money but are received at a later time.

The central issues involved in project evaluation therefore relate to technical and design feasibility and engineering economy.

The following steps are typical for evaluation of alternate energy projects destined to serve remote load centres such as mining developments (Energy, Mines and Resources Canada, 1980). At the preliminary or reconnaissance level where limitations of time and resources enter the evaluation, however, the analyst must make use of a smaller number of critical technical decisions.

1) Study definitions and procedure established
2) Conceptual planning and basic data collection
3) Detailed planning
4) Cost estimation
5) Economic analysis
6) Comparison of alternatives
7) Decision and implementation or . . .
8) Proceed to next level of detail

The basic information needs to complete steps 2 through 6, at the reconnaissance level are discussed below.

Step 2. Conceptual Planning and Basic Data Collection.

Once the scope of the engineering project has been defined and the timing and relationships to other projects have been assessed, it is possible to proceed to the conceptual planning and basic data collection stage. At the end of this stage the analyst hopes to have identified those alternatives which are commercially feasible and for which cost comparisons can be formulated. There are essentially four steps to consider.

i) Alternative selection - Identify alternatives for examination at a preliminary level of detail. This selection is based primarily on technology assessment and energy resource availability. Only commercially available technologies can be compared equally (Ossenbruggen, 1984). If the major project (mine) becomes deferred, advanced energy supply technologies may be progressively considered.

ii) Physical environment for project siting - Determine the physical environment of the proposed energy project, including geography, climate, hydrology, geotechnical, level of certainty of resource supply. Determine the preliminary nature
of any constraints, including environmental, to ascertain the likely costs of mitigation design requirements.

iii) Load demand and growth - Refine the overall project electrical demand and estimate the potential for load growth. Determine the potential nature of waste process heat recovery or other efficiency enhancements.

iv) Preliminary design - On the basis of the foregoing assessments and data, the analyst can plan the preliminary design of civil engineering features for the various alternatives. Major components are access and site preparation, civil, mechanical, and electrical structures, operation and maintenance requirements. For technologies not yet proven commercial, critical information needs in these areas can be identified.

Step 4. Cost Estimation

Cost estimation of preliminary design components is facilitated by judicious reference to standard engineering cost curves and comparison to similar in-service projects. Major cost components vary for different electrical power production technologies—as a comparison of geothermal costs (Roberts, 1978) and hydroelectric costs (Chen, 1979) demonstrate—so these differences and any assumptions must be noted. Generally, for most projects, these components include: capital investment in plant equipment and possibly fuel storage or electricity transmission operating cost, personnel and fuel costs; maintenance costs including replacement equipment,
downtime values, access maintenance; interest on borrowed money, and external management fees; taxes, regulatory, legal and permitting costs.

At the conclusion of this exercise a cost profile range should be available for each alternative.

Step 5. Economic Analysis

The desired outcome of an economic analysis is a measure of the economic feasibility of an engineering project. In general, analyses are carried out using the concepts of capital and consumer theory and time value of money (Ossenbruggen, 1984). Since engineering projects and their effects are often intractable, the analyst must have a means for direct comparison of all benefits and costs. The use of monetary values serves this role. Furthermore, since costs and benefits occur unequally over time, the analyst must consider the time value of money, normally by establishing a discount rate.

Some of the more common methods used to conduct an economic analysis include average annual return, simple payback period, net present value, and discounted cash flow (Johnson and Bennett, 1969). Of these, net present value and discounted cash flow methods are particularly suitable for mining-related economic analysis because they account for a time stream of actual costs and benefits and the time rate of money determined by the investor as an expression of his risk preference, to permit present value calculations. Simple payback is less informative because it ignores costs, benefits, and time value
of money beyond a point in the project's life where the initial investment is recouped.

The financial ingredients of an analysis include: a measure of the initial investment, discounted time stream of operating costs, discounted time stream of anticipated revenues and discount rate preferences of investors. This list is greatly oversimplified and furthermore will be subject to uncertainty in at least the following categories (Raymond, 1976; O'Hara, 1980):

(i) Uncertainty over the geological characteristics of the orebody including grade and distribution of mineralization, mining characteristics of ore, and metallurgical properties of ore which determine metal recoveries.

(ii) Uncertainty over future costs of labour, equipment for mine expansion or replacement equipment, and environmental programs.

(iii) Uncertainty over future expected revenues associated with product prices, smelter costs, and government taxation.

The foregoing list of uncertainties underline the importance of engineering economic analyses to increasingly accommodate risk assessments. The level of risk determination and tolerance is very often an arbitrary appraisal by management which manifests itself in adjustment of the discount rate applied to the time value of money (Lesso, 1982). Higher risk perceptions are reflected in higher discount rates. Sensitivity analysis and Monte Carlo simulation are techniques used increasingly to assess investment risks from a monetary perspective (Harris et al, 1971).

Since the focus of the present study is analysis of
energy supply projects, it is important to mention two commonly used standards of comparison.

The first of these is a gross investment cost per installed unit of capacity, represented as dollars per kilowatt-hour. The second common denominator is referred to as a 'bus-bar' figure of energy cost expressed in mills per kilowatt-hour (mills/kWh). (A mill rate charge of 10 mills/kWh is equivalent to 1 cent per thousand watts of power consumed for one hour.) When both values are low, economic desirability of a project is enhanced.

Step 6. Comparison of Alternatives

On completion of the economic analyses, it is hoped that all projects, having been treated equally, can now be compared. The analyst aspires to have a clear indication of either: (a) the best candidate design, or (b) a much narrower number of alternatives for further detailed analysis.

Summary of Economic Decision Criteria

The following generalized criteria reflect overall economic desirability and efficiency from an engineering perspective on energy project evaluation:

i) Low cost per installed capacity

ii) Low annual energy cost

iii) High rate of return

iv) High system capacity factor
v) Inflation "resistant" fuels
vi) Favourable tax provisions
vii) Well proven and reliable technology with scope for design advancement at low cost

3.3.1.B. Social Benefit-Cost Analysis

i) Introduction to Technique

Residents of northwestern B.C. have a different perception of allocating local resources and the consequences of energy projects for mining than the private firms and residents who wish to see enhancement of mining and energy opportunities. For this reason a social perspective on the evaluation of energy projects requires a conceptual framework within which a broad range of market, non-market and subjective interests can be appraised.

Social benefit-cost analysis is a widely used method purporting to formalize the process of evaluating alternate public and private actions with social consequences (Treasury Board Secretariat, 1976; Hartle, 1979; Pearce, 1971; Pearce and Nash, 1981).

The principal objective of social benefit-cost analysis is to compare social benefits and costs using monetary measures. Where monetary measures, also referred to as efficiency objectives by economists, are inappropriate, benefit-cost analysis offers opportunities to identify trade-offs between non-commensurable objectives, and a means by
which the degree of objective attainment can be assessed (Treasury Board Secretariat, 1976).

The following discussion will review in an abbreviated manner the "standard" approach to benefit-cost analysis as put forward by the Treasury Board Secretariat (1976). While their standard approach has evolved to encompass more ambitious attempts to incorporate intangible data, the author is in agreement with Copp and Levy (1982) who argue that these well meaning ambitions distort and decrease the utility of the concept.

The procedures of social benefit-cost analysis are similar to steps one through seven used by the business analyst as described in the previous section. Essentially this entails estimating the expected rate of return of alternate investment opportunities by estimating and then discounting to the present, monetary flow of benefits and costs for these alternatives. The alternative selected exhibits the highest rate of return, net present value, benefit-cost ratio or other decision rule, given that this rate or ratio exceeds that which is obtainable from investing the funds elsewhere (Hartle, 1979). As simplified as this decision rule may seem, the use of discounted present value as criteria for public investments can become mired by overuse of elaborate formulae and the analyst is constantly urged to examine these criteria from a simplified perspective (Mishan, 1980).

Social benefit-cost analysis does have procedural differences from the business analyst's approach. Regarding
the previously outlined seven steps, these differences concern additional emphasis placed on identification of social and physical constraints during planning and conceptualizing the project, and the quantification of a greater range of social, environmental, and external benefits and costs and generally a greater attempt at noting their distributional effects.

ii) Basic Tenets

Social benefit-cost analysis includes the following basic tenets:

a) Rational choice from a social perspective uses a broader definition for the criterion, economic efficiency, than a private perspective. This stems from a social desire to maximize human welfare and therefore criteria must additionally encompass a broad range of intangibles such as amenity or cultural resources. To ignore this social vs. private discrepancy, risks misallocation of resources (Hartle, 1979).

b) Since benefit-cost analysis uses monetary measures as a basis for comparison, non-market goods valued by society must have imputed dollar values (shadow prices) assigned to them (Treasury Board Secretariat, 1976). Willingness to pay is a criterion used to establish imputed values although comparison with the criterion of minimum compensation would seem prudent (Banford, Knetsch, Mauser, 1980).

c) As the magnitude of imputed costs and benefits increases relative to market costs and benefits, the analysis will be more subjective and offer less convincing guidance to
decision makers (Hartle, 1979).

d) ... benefit-cost analysis rarely achieves the ideal of measuring all benefits and costs in money terms, and must therefore be accompanied by indicators of the non-efficiency objectives for decision-making at the political level. (Treasury Board Secretariat, 1976)

iii) Limitations of the Techniques

Having thus introduced social benefit-cost analysis, the remainder of the discussion will concentrate on the common limitations of the concept and some considerations for application to energy project analysis.

The following problem areas potentially limit the usefulness of social benefit-cost analysis and therefore require specific attention.

a) Values - Despite the intent of social benefit cost-analysis to be objective, which implies somehow being value free, there are three reasons for a contrary view. First, values are included only when they can be represented in the market, and therefore non-market values are omitted. Secondly, a social perspective that extends rationality in decision-making beyond economic efficiency must depend on judgement exercised by the analyst to determine the kinds and nature of non-market values and their appropriate discount rates to be included in the analysis (Copp and Levy, 1982). Thirdly, imputed values for non-market items, usually reflect analyst's or consumer's willingness to pay bias.

b) Treatment of Time - The choice of an appropriate discount rate is vital to the analysis as this will affect the
profile of the stream of benefits and costs obtained unequally over time (McAllister, 1980). The use of a high social rate of discount will tend to favour private business investments and short-term public programs. Conversely, the use of a low social rate of discount will increase the number of long-term capital intensive projects and favour future generations. Arguments supporting higher or lower discount rates relate to economic perceptions of efficiency, and as Pearce and Nash (1981, p. 164) have pointed out, is the subject of equivocal consensus for both present and future generations. A logical approach is to test the sensitivity of results to a range of discount rates (Treasury Board Secretariat, 1976, p. 26).

c) Shadow Prices - Shadow prices are the imputed prices of allocative benefits and costs determined in the absence of, or presence of distorted, market prices (Treasury Board Secretariat, 1976). The obvious difficulties stem from deciding whose values are to be used for assignment of shadow prices and in the assessment of how far shadow prices have influenced benefit-cost analysis beyond standard non-shadow priced efficiency criteria (Copp and Levy, 1982).

d) Risk and Uncertainty - The conceptual basis for risk and uncertainty was outlined in section 3.2.2. Concerning risk, one standard approach is to "'adjust' our decision rule in such a way that the cost of risk-bearing (CRB) is deducted from the expected value of the net social benefit of the project" (Pearce and Nash, 1981, p. 69). The common way of accounting for this adjustment is through a modified discount
rate; a "risky" discount rate is higher than a "risk-less" discount rate.

The central problem of uncertainty in social benefit-cost analysis concerns the difficulty of assigning prices to uncertain events whose probabilities cannot be determined. Thus, there is no generally acceptable method of formally treating uncertainty in social benefit-cost analysis (McAllister, 1980). Multi-criteria decision-making techniques such as sensitivity analysis can test the limits of risk but cannot eliminate uncertainty. As a result, key uncertainties are ultimately best resolved through the political process, after much analyses.

e) Distributional Effects - Social benefit-cost analysis requires explicit reference to the important distributional effects of alternate project costs and benefits in order to gauge the degree to which the public's varying objectives have been realized. Moreover, distributional effects connote equity, and equity includes fairness to future generations (Ramsay, 1981). The inclusion of these factors into the standard decision rule criteria is less than persuasive (Hartle, 1979).

f) Externalities - The concept of externalities was described in Section 3.3.1. In the context of social benefit-cost analysis externalities concern "Costs or benefits which do not contribute to the individual firm's or consumer's decisions . . ." (Eden et al, 1981, p. 216). The extent to which externalities are included in the analysis rests with the
method of imputing shadow prices.

g) Summary - There are no "special" or "mysterious" applications of social benefit-cost analysis to the evaluation of energy projects. The main virtue of social benefit-cost analysis in energy project assessments at the reconnaissance level lies in its capacity to account for and clearly express social and environmental benefits and costs external to the concerns of the firm initiating the energy project. Indeed social benefit-cost analysis is clearly a public decision-making tool, permitting a wide range of public perceptions on risk, resource allocation, and consequences of lifestyle changes, for example, to guide the choice of alternate energy projects. A firm will be adverse to internalizing these concerns without an external social compulsion to do so, as any related costs will unnecessarily deteriorate the profitability of an investment. Alternatives that "fail" or "pass" the business analyst's approach, but which have significant social virtue, or marginal social benefit respectively, can be identified for further detailed investigation. As a hypothetical example of the latter, the result of including social objectives in the benefit-cost ledger might cause a less technically efficient and more land use intensive energy technology to be considered in preference to other alternatives if greater employment and enhanced manufacturing opportunities were afforded.

Not all external consequences of energy projects will be quantifiable in a social benefit cost approach, however the
technique enhances the precision with which they are identified; the anticipated net result will be better informed political decisions.

3.3.1.C. Public Energy Policy

i) Conceptual Basis for Policy

The dramatic world rise in the price of petroleum-derived fuels in the mid-1970's caused virtually every nation to re-examine its long-term energy futures. The Canadian self-examination has shifted gradually from a preoccupation with petroleum and nuclear energy to a more balanced strategy advocating "multiple-option, regionally oriented energy supply" (Energy, Mines and Resources, 1976; 1977; Department of the Environment, 1982). Throughout, the Canadian goal of energy self-reliance has been paramount (Energy, Mines and Resources, 1976; Science Council of Canada, 1979). In comparison, the goal of self-sufficiency has evoked considerable public debate (Ross, 1980; McNicholas, 1980; Gorbet, 1980; Swain et al, 1979).

Stated provincial objectives in general have mirrored national goals as illustrated by the following British Columbia Ministry of Energy, Mines and Petroleum Resources' (1980) energy policy statement.

Energy security is the fundamental objective of British Columbia's energy policy. Energy security means that sufficient energy is available to meet our demands— at all times, at fair market prices, and with as little vulnerability to external forces as possible.

It is also the aim of the Government's policy to
achieve energy security in accordance with the priorities of its overall social and economic policy: increasing stability, employment and income growth, maintaining high standards of environmental quality, and balancing regional development.

Clearly the inseparable link between the development of energy resources, at any scale, and the desire to maximize the economic and social well-being of society will be the guiding impetus of future energy policies.

In recent years, Canadian industry accounted for about 32 percent of national energy use (Ministry of State Science and Technology, 1982). This compares with about 49 percent of British Columbia's energy budget being consumed by industry (British Columbia Energy Commission, 1978). Mining, as a major part of the provincial industrial economy, is acknowledged as one of the more energy intensive sectors (Energy, Mines and Resources, 1976; Joe, 1979; Ministry of Energy, Mines and Petroleum Resources, 1980). In 1979 for example, 62.46 petajoules (PJ), equivalent to 15% of industrial and 7.3% of Provincial consumption, were consumed by the mining and primary minerals industry (Ministry of Energy, Mines and Petroleum Resources, 1981). Given the magnitude and energy intensive nature of mining it can be expected that energy consumption at newly developed mines will continue to come under public scrutiny to assess whether energy economics and supply are consistent with the aspirations of political and regional entities with respect to security of energy supply, and betterment of social welfare.
ii) Evaluation Criteria

The cornerstone national and provincial energy policies are the criteria for this evaluation. Policies potentially relevant to the energy supply situation for mining in northwest B.C. are listed below.

i) capitalize on indigenous energy resources.

ii) encourage substitution off oil at existing oil-fired electrical generation facilities, and for petroleum fuel based transportation systems.

iii) encourage conservation through efficient energy use, i.e., cogeneration, waste heat recovery.

iv) encourage use of renewable energy technologies.

v) increase efficiency in energy conversion, transport, storage, materials handling, and processing activities.

vi) expand research and development of more efficient and environmentally benign energy conversion technologies.

vii) evaluate total system efficiencies through an energy balance framework such as net energy analysis.

iii) Summary

The implementation of these policies for mining endeavours in northwest B.C. will be tempered by practical constraints imposed by climate, geography, duration of mining activities, remoteness, and environmental and social uncertainties. Mining companies will be voluntarily motivated to pursue efficient energy designs because the need to be self-reliant will have effectively internalized many of the
costs of energy production. As well, the potential feasibility of new mines can be regarded as sensitive to energy costs, since these now exceed 13 percent of total production costs (Mining Association of British Columbia, 1983).

An excellent example of such voluntary motivation is the Polaris Mine on Little Cornwallis Island in the Arctic, where a total energy concept utilizing the efficiency criteria of maximum waste heat recovery and optimum equipment reliability at an integrated mine/mill/settlement complex achieved maximum efficiency in terms of energy input of 96 percent, discounting auxiliary power plants (Nielsen, 1984).

3.3.1.D. Institutional Considerations

Many public objectives concerning health and environmental protection, social equity, and management of crown resources are attained through government enacted legislation and corresponding regulations.

Several recent studies which investigated the opportunities for the private sector to develop small scale energy projects in British Columbia have cited institutional uncertainties as potential constraints to project development (Nevin Sadlier-Brown Goodbrand, 1981; Sigma Engineering Limited, 1984; Crippen Consultants, 1980).

The criteria (constraints) fall into two categories: government regulations and incentives, and private financing.
i) Government Regulations and Incentives

In the first category are included regulatory activities pertaining to application and permitting of energy projects, health and safety standards during construction, operation and maintenance, design standards, and environmental protection. Table V outlines legislation with possible implications for energy projects depending on the type of project, its scale, timing and siting. It is beyond the scope of the present study to summarize each piece of legislation; the point is to indicate to the analyst the types of legislation of possible importance to the preliminary evaluation of alternate projects.

Government incentives related to power generation projects in the private sector exist at both the federal and provincial level. Incentives may occur in the area of resource supply assessment, as advocated for geothermal by Nevin Sadlier-Brown Goodbrand (1981), or as incentives linked to use of improved conventional or nonconventional energy conversion technologies, such as those promoting less dependence on oil-fired fuels.
### TABLE V

**B.C. Provincial Legislation with Implications for Energy**

<table>
<thead>
<tr>
<th>Act Name</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>B.C. UTILITIES COMMISSION ACT</td>
<td>c.60</td>
</tr>
<tr>
<td>COAL MINE ACT</td>
<td>c.51</td>
</tr>
<tr>
<td>COAL ACT</td>
<td>c.52</td>
</tr>
<tr>
<td>ELECTRICAL ENERGY INSPECTION ACT</td>
<td>c.194</td>
</tr>
<tr>
<td>ENVIRONMENT MANAGEMENT ACT</td>
<td></td>
</tr>
<tr>
<td>FISHERIES ACT</td>
<td>c.137</td>
</tr>
<tr>
<td>FOREST ACT</td>
<td>c.140</td>
</tr>
<tr>
<td>GEOTHERMAL RESOURCES ACT</td>
<td>c.154</td>
</tr>
<tr>
<td>GREENBELT ACT</td>
<td>c.157</td>
</tr>
<tr>
<td>HERITAGE CONSERVATION ACT</td>
<td>c.165</td>
</tr>
<tr>
<td>LAND ACT</td>
<td>c.214</td>
</tr>
<tr>
<td>MINES ACT</td>
<td>c.263.5</td>
</tr>
<tr>
<td>MINING REGULATION ACT</td>
<td>c.265</td>
</tr>
<tr>
<td>MINING RIGHT OF WAY ACT</td>
<td>c.266</td>
</tr>
<tr>
<td>PARK ACT</td>
<td>c.309</td>
</tr>
<tr>
<td>PIPELINE ACT</td>
<td>c.328</td>
</tr>
<tr>
<td>WASTE MANAGEMENT ACT</td>
<td></td>
</tr>
<tr>
<td>WATER ACT</td>
<td>c.429</td>
</tr>
<tr>
<td>WATER UTILITY</td>
<td>c.430</td>
</tr>
<tr>
<td>WILDLIFE ACT</td>
<td>c.433</td>
</tr>
</tbody>
</table>
Incentives are also available in relation to increased local employment or job training. The net favourable results of government incentives would be to enhance the economic attractiveness of the qualifying energy project while simultaneously providing previously unavailable social benefits to the region.

ii) Private Financing

Financing is the second criterion identified above. Where a mining company is required to seek commercial financing to construct energy supply facilities, the feasibility of certain projects may be disadvantaged. In particular, for alternatives such as small hydro, geothermal, and certain coal generation technologies, where initial capital expenditures are high but net unit energy costs decline over the project life, several initial years of negative cash flow are anticipated. Even though the project is financially viable on a net present value basis, financing by conventional level payment, declining balance loans may be difficult (Sigma Engineering Ltd., 1984). For a mine development anticipated to have a short life, for example less than 10 years, commercial financing flexibility may be an important determinant for energy supply feasibility.

3.4. SUMMARY

This chapter has presented overviews of evaluation theory in two parts. The first part introduced the concept of
normative evaluation as determined from the literature on planning and decision theory. The latter part considered how various public and private objectives manifest themselves in the evaluation frameworks commonly adopted to serve these interests. Special reference is made to the energy supply situation for mining in northwestern B.C.

The normative evaluation process is characterized by the following basic steps:

1) Identification or formulation of the problem and clarification of objectives.

2) Conceptualization of alternatives through examination of data and relationships.

3) Evaluation of alternatives according to mutually exclusive criteria.

4) Interpretation of the results and derivation of conclusions prior to recommendation, implementation or further review, and

5) Monitoring of the results and where possible verification of earlier conclusions.

Variations of this basic procedure arise because of differing perceptions of the techniques to optimize the four characteristic technical-political trade-offs that pervade such processes.

Hickling (1975) has aptly summarized these trade-offs as follows:

The first 'tradeoff' concerns the balance between simplification and the recognition of complexity—the extent to which a problem can be simplified in order to
deal with its inherent complexity without sacrificing the validity of the solution. . . . The second is the conflict between urgency and the lack of information—between the pressure to make a decision, and the need to collect enough information to do so scientifically. The third has to do with commitment and flexibility—the balance which has to be found between the need for commitment and the desirability of keeping one's options open. And the fourth is between incrementality and comprehensiveness in decision-making. Decisions are more often than not reached in a piecemeal fashion; problems are not necessarily completely solved in one go—frequently parts of plans are decided, leaving the rest to be further examined later as part of an overall process of recycling.

Permeating all this is the concept of uncertainty. Uncertainty exists principally because of knowledge deficits, arising from inadequately understood system relationships. Uncertainty cannot be ignored and therefore must be dealt with through various practical and specialized analytical techniques such as sensitivity analysis and advanced decision theory.

The second part of the chapter examined applications of the normative framework by focusing specifically on the evaluation framework and criteria dominating engineering, social benefit-cost, and public energy policy objectives. It was concluded on the basis of the range of public and private preferences relating to northwestern resource management that these frameworks could best encompass the critical criteria necessary to evaluate energy options.

The principal engineering project criteria of interest to the private firm that were identified, included the following: cost per installed capacity ($/kW), energy cost (mills/kWh), net present value, simple payback, technological and energy
resource feasibility, and system capacity factors.

Criteria identified for a public or governmental social benefit-cost perspective, generally include: net present values and possibly benefit/cost ratios, based on a tabulation of the benefits and costs related to human resources, local income and employment, community well-being, biophysical impact, impact on government and institutional structures. Distributional effects and non-quantifiable benefits and costs should also be identified.

Public energy policy related to attainment of national self-reliance in energy comprises the ultimate facet of energy project evaluation that was considered. Criteria reflected broad level national provincial policies advocating a long-term view towards wise and efficient use of energy resources. Conservation, efficient use, investment in research and development, and the use of energy auditing procedures are bench-mark indicators that public policies are being pursued.

Institutional considerations for energy project evaluation that were briefly noted, include government legislation and regulations, and government incentives. Flexibility and ease of energy project financing was also noted as important to mine developers who would require commercial financing of uncommonly employed or unconventional energy supply projects.

To conclude, it is evident that permutations of the fundamental tenets of normative evaluation can address the information needs corresponding to society's differing
objectives. Understanding the basic and specific techniques allows for a range of priority criteria to be identified. These can subsequently be used to derive a strategic approach to resolving shared but differently perceived problems.
4.1 PURPOSE:

The purpose of this chapter is to present a methodology for the reconnaissance level evaluation of energy supply alternatives for the development of medium scale mineral deposits in northwestern B.C. The methodology is based on evaluation frameworks reviewed in Chapter 3 and elements of a strategic approach to policy and analysis as described in the present chapter. The chapter concludes by discussing the limitations of the proposed methodology.

4.2 ELEMENTS OF A STRATEGIC METHODOLOGY:

A strategic approach to policy analysis can be defined as simply a way of dealing with interconnected decision areas in an uncertain environment (Hickling, 1975; Fox et al., 1982). Emphasis is placed on identifying priorities for investigation, understanding the interrelationships between information and decision components, and managing for uncertainty, rather than on the task of arriving at an answer to the problem in the most expedient manner.

The successful strategic approach includes the concept of iterative analysis to account for changing problem dimensions and to keep the analysis focused over lengthy periods of time. Insofar as a strategic approach is successful, it will provide
guidance for better quality decisions today, where the consequences will be felt in an uncertain future. As Clarkson (1981) has poignantly noted, surprise is the antithesis of successful strategic planning.

Attributes and principles which commonly form the strategic basis of many policy analysis frameworks are well documented in the literature (Hickling, 1975; Ansoff, 1977; King and Cleland, 1978; Holling, 1978; Fox et al., 1983; and Ascher and Overholt, 1983). The following attributes and criteria are considered especially relevant to the strategic reconnaissance level methodology proposed in the present study;

i) Emphasis on priorities - Critical attention must be focused during the strategic analysis on determining the priority valuation and evaluation criteria which measure the attainment of these objectives. Two purposes are served by this emphasis; it promotes the efficient use of scarce analytical resources, and it ensures that only the most relevant and useful types of information are brought to bear on the resolution of the problem. In this way the strategic analysis can respond to, and measure benefits and costs of opportunities, constraints, and surprises as they arise.

ii) Continuity of analysis - Strategic analysis must be a continuing and an iterative process, to provide a comprehensive and coherent perspective on the decision environment and its possible solutions, not obtainable from a once-through evaluation. Thus with the analyst constantly alert to new and changing information, the reliability of results will therefore
be enhanced.

iii) Robustness - A methodology is robust if its conceptual framework and analytic processes are insensitive to the resolution of those uncertainties outside of the decision environment or the analyst's control. Moreover, a robust methodology contains the ability to accommodate and respond positively to changes in external uncertainties.

iv) Adaptiveness - A strategic methodology is adaptive if current decision choices are interchangeable and future options are maintained. Adaptiveness should be distinguished from reversibility which relates to the potential for undoing the consequences of implemented decisions. The degree of adaptiveness can be judged by the extent to which the analysis can respond at the right time with information needed to influence eventual project selection and development. Since it is neither possible, nor desirable, to remove all uncertainty from the analysis, it is necessary for the analytic framework to remain adaptive.

The foregoing attributes and criteria must have expression in a conceptual framework if a strategic approach is to be truly achieved. In a reconnaissance level analytical framework, the degree to which they are manifest is determined by the trade-off between simplicity and complexity. Simplification permits comprehension, a perspective with understanding and insight on the process of analysis as it relates to the component parts, in order to arrive at the
desired decision. Complexity allows details of objectives, data and other interactions to be developed so that rigour and reliability are maintained.

In summary, the concept of a strategic approach to methodological development emphasizes the interrelationships of structure and organization, information, and decision components in the evaluation process. By incorporating attributes of priority emphasis, continuity, robustness, and adaptiveness, a strategic methodology maintains a high level of responsiveness to an uncertain problem environment.

The methodological framework presented in the following section for the evaluation of energy alternatives incorporates the foregoing premises of a strategic approach.

4.3 METHODOLOGY:

4.3.1 Introduction

This section is structured in two parts, consisting initially of the methodology's basic structure, and secondly, an outline of the principal elements of the main structural parts. Diagrams supplement the text.

The intent of the methodology is made clearer by an explicit understanding of two frequently used terms; reconnaissance and strategic.

The use of "reconnaissance" underlines an intent to structure the methodology, at an appropriate level of complexity and comprehensiveness, to deal with preliminary information regarding energy supply alternatives such that a
Figure 8. Generalized Methodology Structure
Prefeasibility level of analysis may be subsequently entered into on the basis of a narrowed set of alternatives. Preliminary information is that which is available without field visitations or special expenditures of funds.

"Strategic" refers to emphasis placed on the process, its interrelationships and management of uncertainty (Hickling, 1975). The importance and attributes of a strategic approach were discussed in Section 4.2.

The anticipated effect of emphasizing these two concepts is a demonstrable reduction in uncertainty facing future decisions.

4.3.2. Proposed Framework

The methodology is comprised of three main structural parts: the core information environment, and the basic and peripheral evaluation environments.

The core information environment identifies and focuses on the problem of energy supply for a particular undeveloped mineral deposit; the basic evaluation environment assesses the viability of potential alternatives through the application of multiple criteria; while the peripheral environment covers strategic information, independent of the focused problem, that influences both the core and basic environments. Figure 8 illustrates their general relationships. The arrows denote the direction of information flows and suggest that various parts of the analysis can be carried out simultaneously or more than once.
Each evaluation environment contains strategic data bases and analytical processes designed to answer specific questions so that the analyst can proceed from initial problem identification to selection of key alternatives.

Strategic data bases are collections of critical, related information (i.e., technical, political) from which conclusions can be drawn to advance the understanding of the problem environment or potential solutions. The relevant information contained in a strategic data base must be continually updated and analyzed to maintain the readiness of the overall analytical framework's response to changing external stimuli.

The circular arrow bounding each evaluation environment in Figure 8 represents the iterative nature of these internal analyses. The circular arrow for the peripheral environment is shown as intermittent to acknowledge that the information contained in its strategic data base is subject to a greater degree of uncertainty.

Conclusions drawn from strategic data bases at various points in the analysis permit the construction of scenarios. A scenario is a portrayal of the relationships of the perceived problem to its environment under existing assumptions and perceptions. Scenarios constructed early in the analysis are of the exploratory type; they start with historical circumstances, proceeding up to the present, and explore trends and alternative futures based on a careful hypothesizing of a perceived logical sequence of events. By comparison, scenarios developed at the conclusion of the analysis are of the
anticipatory type; they conceptualize feasible and desirable futures based on a refined set of objectives and investigate the feasible alternatives and acceptable consequences necessary to achieve these futures. Scenario construction is vital to policy formulation and analytical resource allocation.

Thus far the discussion has dealt with structural elements and processes of the overall methodological framework. It is now necessary to describe in greater detail the functional aspects of the core, basic, and peripheral environments.
Strategic Data Base Sets

Strategic Data Base 1
Interest Groups and Objectives
i) Identify Interest Groups and Objectives
ii) Determine Objective Functions and Corresponding Variables
iii) Examine Risks; related perceptions and management strategies

Strategic Data Base 2
Energy Demand
i) Identify Mineral Deposit Characteristics; geology, physical, historical
ii) Determine Conceptual Model for Processing and Development
iii) Derive a Range of Energy Demand Estimates Based on Various Production Schedules

Strategic Data Base 3
Regional Influences
i) Identify and Examine Regional Influences;
   - nearby mineral deposit development
   - nearby non-mineral industrial development
   - status of native land claims
   - major land use planning programs

Determine Perspective for Subsequent Evaluation

Figure 9. Core Information Environment
4.3.2.A. Core Information Environment

The core information environment identifies and focuses on the problem of energy supply for medium-scale mining. It estimates the boundary, scope, scale, and timing of the energy supply problem for a deposit as well as identifies the principal interests likely to be involved in future decisions.

Three strategic data base sets are developed for the core information environment. These cover:

a) mineral deposit geological parameters
b) key participants and their objective functions, and

c) external factors such as mineral development and economic trends, regional population growth, and land use patterns.

The core information environment purports to seek answers to the following key questions:

1) What is the nature of the problem identified? How is the problem perceived in current scenarios of mineral development?

2) From whose perspective has the problem been identified and the scenario constructed?

3) Who are the interest groups involved in the analysis?

4) What are the interest groups involved in the analysis?

5) How can the components of the objective functions be utilized to focus the problem?
6) What is the nature of peripheral influences on problem definition?

7) What is the nature of the focused problem?

8) How is the focused problem expressed in a modified scenario of mineral development?

Not all of these questions may be answerable in a first attempt, and it may be necessary to proceed with the analysis, cycling back to complete focusing of the problem at a later time.

Figure 9 provides a simplified illustration of the interrelationships between key components of the core information environment.

4.3.2.B. Basic Evaluation Environment

The basic evaluation environment delineates power generation alternatives and applies multiobjective criteria to the alternatives to derive a data base that can be used to assess the ability of each alternative to resolve the focused problem. Based on multiattribute decision-making techniques such as dominance and satisficing, a narrowed set of "most likely" alternatives is defined. These alternatives can be advanced to the prefeasibility stage.

Strategic data base sets developed for the basic evaluation environment cover:

a) energy resource supply

b) energy conversion technologies, economics, and development trends, and
c) power generation-related, regional environmental, and social opportunities and risks.

The basic evaluation environment attempts to satisfy the following questions and information requirements:

1) What are the particular energy supply alternatives for a particular mineral deposit?

2) How does the analytical framework address the objective functions identified in the core information environment?

3) From whose perspective is the evaluation conducted?

4) What are the priority valuative criteria used to assess the alternatives?

5) On the basis of a formal application of multicriteria decision-making procedures, which alternative(s) is (are) best suited to supply energy to the potential mine?

6) What is the nature of the anticipatory scenario derived from the basic evaluation environment?

4.3.2.C. Peripheral Evaluation Environment

The peripheral evaluation environment covers strategic information which influences the core and basic evaluation environments, but is essentially independent of the focused problem.

The peripheral evaluation environment does not contain an analytical process analogous to the other
FOCUSED PROBLEM

IDENTIFY PRIORITY
EVALUATIVE CRITERIA

CONCEPTUALIZE
ALTERNATIVES

Determine Research Requirements of Strategic Data Base Sets

Energy Resource Supply Technology Economics Environmental Opportunities and Risks Social Opportunities and Risks

Apply Criteria to Alternatives Based on Collected Data

Apply Formal Multi-Criteria Decision-Making Procedures
(i) Satisficing - set minimal initial conditions (ii) Dominance - examine objective function and indicate preference for alternatives - examine constraints imposed by external objective function variables - examine areas of risk (iii) Interpret, Select and Rank Narrowed Set of Alternatives

Proceed to Prefeasibility Analysis

Figure 10. Basic Evaluation Environment
structural parts. Rather, it provides a strategic information input mechanism at various stages of the other evaluation environments, to assist in reducing uncertainty and adjusting the direction of the ongoing analyses.

Strategic data base sets of the peripheral evaluation environment cover the following four areas:

a) status of mineral deposit developments adjacent to the deposit being reviewed,

b) mineral commodity price, demand, and supply trends,

c) government policy with application to regional mineral development, and

d) changing land use patterns adjacent to the mineral deposit. Where competing resource use potentially alters the tenor of anticipated energy project impacts and costs.

Information on the external consequences of alternatives, which are identified in the basic evaluation environment, when considered together with the above strategic data bases, provides an understanding of the distributional effects of implementing alternatives, and aids in the construction of scenarios.

4.4 LIMITATIONS:

Implementing the methodology is limited by a number of considerations pertaining to its structure and practicability. Limitations stem from the trade-offs between simplicity and
complexity, incrementality and comprehensiveness, level of analytical resources, and uncertainty.

Simplicity and complexity concern the level at which comprehension of the analytical process is achieved at the expense of a detailed and rigorous yet less comprehensible analysis. Undoubtedly, the reviewer's prior exposure to concepts in policy analysis will dictate this assessment to some degree.

Data availability and the cost of data processing limit the trade-off between incrementality and comprehensiveness. Because of the preliminary nature of the analysis, comprehensive data will not be attainable, or attainable at high cost, and it may therefore become impossible to carry through the analysis without incremental and recursive steps. Moreover, the aspired level of confidence in results will vary from one deposit to another owing to the status of exploration and the quality of information available.

Cost of resources required to conduct the analysis is unclear. However, it is likely there will be no immediate return, and no guarantee of long-term return, unless production is achieved. A dilemma therefore arises; does one conduct analyses on energy supply options if the feasibility of the deposit is in doubt, or cannot be demonstrated, or does one wait till the deposit is proven feasible, at risk of dealing with a narrowed set of future energy supply alternatives?

The degree to which uncertainty prevails is difficult to determine in advance. While the methodology has ostensibly
attempted to internalize the three kinds of uncertainty—uncertainty in the operating environment, uncertainty in values, and uncertainty in decisions external to the problem environment—principally through the use of strategic data bases, nevertheless there are likely to be many areas where further uncertainty becomes evident.

The final limitation relates to the analytical environment. For the analysis to be truly strategic in nature requires commitment and will of the analyst; to update strategic data bases, continually reassess interest group relevance and objectives, and proceed with the analysis even though the timing of the mineral development is uncertain.

4.5 CONCLUSIONS:

A methodology has been presented for strategic reconnaissance evaluation of energy supply alternatives for mineral deposit development in northwestern B.C.

The methodology incorporates principles of normative analysis to proceed logically from problem identification to resolution. These principles are augmented by specific evaluation procedures which reflect the objectives of key decision participants.

The methodology's structure entails three main components; a core information environment and basic and peripheral evaluation environments, each with its corresponding strategic data bases and internal analytic processes.

To achieve a strategic level of analysis at the
reconnaissance level, the structural components have been designed to promote emphasis on priorities, continuity of analyses, robustness, and adaptiveness. A desired balance between simplicity and complexity can be achieved in the analysis by acknowledging the limitations imposed by the interaction between analytical design, physical resources, and uncertainty.

The stage has thus been set for the analyst to carry out a practical application of the methodology.
This chapter introduces the RED-CHRIS copper-gold deposit which has been selected for application of the energy supply evaluation methodology proposed in Chapter 4.

Exploration history of RED-CHRIS is reviewed and a range of electrical energy demands, anticipated for eventual production, are derived by reviewing standard mining and milling energy consumption data and applying these results to various assumed production schedules.

The deposit will not be modelled, nor will a detailed input-output energy analysis be performed as these exercises exceed the scope and resources available for the present reconnaissance study.

The information presented in this chapter provides a basis for subsequent detailed examination of the deposit's energy supply situation.

The RED-CHRIS deposit, centrally located in the study area at approximately 57°41'N. latitude and 129°48'W. longitude, is shown on Figure 2-2. It is selected as a case study for the following reasons:

1) RED-CHRIS contains two of the region's principal commodities, copper and gold, and meets the medium-size criteria in terms of in-situ reserve value and energy demand as defined in Chapter 2.

ii) RED-CHRIS is well explored and considered to be at
the prefeasibility stage of development.

iii) RED-CHRIS experiences a mix of development constraints such as weak metal prices and lack of infrastructure which are typical for many deposits in the region.

iv) The deposit's location lends itself to consideration of a variety of energy supply alternatives.

v) The writer brings first-hand knowledge of the deposit to the analysis, having spent all or part of five field seasons engaged in exploration on and adjacent to RED-CHRIS.

5.1 HISTORY OF EXPLORATION AND RESERVES

Mineral exploration has occurred throughout the Stikine area for nearly 100 years. Prior to 1898 the earliest prospecting activity concentrated primarily on placer gold deposits. This activity was centred north of the Stikine River from Glenora to Dease Lake. With the discovery of the Yukon placer fields, Glenora and later Telegraph Creek became the favoured disembarking locations for the Klondike from 1898 to about 1900. Later, the majority of traffic diverted to Juneau and the Chilkoot Pass trail (Alaska Geographic, 1979).

Exploration in the early 1900's resulted in the discovery of numerous copper, lead, zinc, molybdenum, gold and silver mineralized prospects. Many copper and molybdenum prospects were re-evaluated during the 1950's and 1960's with the increasing interest in large low-grade "porphyry" deposits. This was spurred on by steadily rising metal prices and
advances in metallurgical recovery technology allowing the exploitation of lower grade ores. The Canadian Institute of Mining and Metallurgy (1976) describes some of the more important deposits in the region.

Newell and Leitch (1976) have reviewed the history of the RED-CHRIS porphyry copper-gold deposit for the period 1969-1976. The salient features of their review are as follows. Exploration began in earnest on a portion of the RED-CHRIS deposit in 1969 when Great Plains Development Company of Canada Ltd., (now Norcen) located the Chris and Money claims south of the present deposit. Preliminary exploration concentrated on mineralized showings in deeply incised drainages and consisted mainly of geological mapping and geochemical sampling. Subsequently about 1230 metres of diamond drilling were completed by 1972.

The adjoining property to the east, comprised of the Red and Sus claims, were located by Silver Standard Mines Ltd. in 1970. In 1971 their field programme consisted of geological mapping, geochemical and geophysical surveys and 457 metres of trenching. No work was carried out in 1972.

Ecstall Mining Ltd., (later Texasgulf Canada Ltd., and now Kidd Creek Mines Ltd.) became interested in the RED property as a result of a submittal of the ground by Silver Standard for examination to Ecstall's parent company Texasgulf Inc. An agreement was reached in 1973 and Texasgulf Inc. proceeded to carry out a programme of percussion drilling totalling 915 metres. Results were sufficiently encouraging to
lead to an agreement with Great Plains to further explore the Chris property. Exploration from 1974 through to 1980 included extensive surface geological and geochemical work along with underground geophysics and drilling. To date a total of 75 diamond drill holes totalling 13,119 metres and 44 percussion drill holes totalling 3,178 metres have been completed (Peatfield, 1980).

Results of this work have outlined a modest deposit containing 41 million tonnes of undiluted "ore" with an average grade of 0.56% copper and 0.34 gram/tonne gold, based on a stripping ratio of 1.4:1. The reserve calculations use an arbitrary cut-off grade of 0.25% copper. Total contained metal based on this cut-off grade is 229,600,000 kg copper and 13,940,000 gm gold. The total value of the deposit is therefore $630,750,000 based on $1.80/kg copper, and $15.60/gm gold (producer prices mid-June 1984).

The deposit occurs in two zones, the Main and East zones, containing 34.38 and 6.62 million tonnes of drill indicated reserves, respectively. The Main and shallower parts of the East Zone would be amenable to open-pit mining methods. Higher grade "ore shoots" at considerable depth in the East Zone may require underground development.

Panteleyev (1975, 1977) has summarized the geology of the deposit. Essentially, two zones (Main and East) of copper-gold stockwork mineralization occur within an elongate highly altered subvolcanic intrusive complex of monzonitic composition, enclosed by andesitic to basaltic volcanics and
volcaniclastics of Late Triassic age.

5.2 **POWER REQUIREMENTS:**

The anticipated average demand for electrical energy by the potential RED-CHRIS mine is subject to uncertainty resulting from unknown scale and duration of future mining operations. However, it is possible to constrain energy demand projections if one proceeds with two hypothetical ranges of production reflecting typical disinvestment periods used in the mining industry for this scale of deposit. In this way upper and lower bounds for energy demands can be determined.

The following assumptions are applied.

i) That the mine will operate for between 8 and 20 years. Previous studies have suggested potential durations of mining of 29 years (Interministry Working Group on Northwest B.C. and Ministry of Energy, Mines and Petroleum Resources, 1983), and 20 years (Schroeter and Pan, 1982).

ii) Extraction will be based on an optimal investment strategy where an initial stock of capital achieves constant rate of production over the mine's life (Campbell, 1980). In practice, extraction and investment policies are likely to be less than optimal and production rates will vary in response to current economic and labour situations. An attempt to forecast these variations could lead to spurious results.

iii) Production will occur entirely from an open-pit operation because of the difficulties encountered in trying to forecast the higher energy demands of an underground or
combined open-pit/underground operation.

iv) A stripping ratio of 1.4 tonnes of waste rock per tonne of ore is assumed, as this is the ratio used for ore reserve estimations.

Chapman and Roberts (1983) and Joe (1979) have summarized energy consumption data for mining and milling stages of low-grade open-pit copper deposits.

Energy requirements of mining, the removal and transport of waste and ore to the dump pile and mill, depend on a variety of factors including: mining methods, rock hardness, equipment used, scale of operation, distance from mine to mill, climatic conditions, and local geography. Milling, the process of upgrading mineralization to produce metal concentrates, depends on factors such as fineness of crushing and grinding, methods of separation and concentration, and product concentrate preparation by drying and packaging.

Chapman and Roberts (1983) present data from Batelle (1975) and U.S. Department of Interior studies that indicate gross energy requirements for open-pit copper mining and milling to be 15 to 32 MJ/ton ore mined (1.46-3.14kWh/tonne), and 272 MJ/ton ore milled (26.6kWh/tonne). This assumes a conversion of 11.25 MJ/kWh @ 32% efficiency.

Joe's (1979) results for energy consumption in milling of copper ores in Canada, indicate a mean requirement of 215.5 BTU/ton ore (23.75kWh/tonne @ 10^4 BTU/kWh).

By inference, mining and milling of RED-CHRIS ore could be expected to entail gross energy requirements in the range of
25.21 kWh/tonne to 29.74 kWh/tonne exclusive of waste rock stripping energy requirements and byproduct concentration.

The following calculations of potential energy capacity requirements are derived using the foregoing data. For comparison, previous workers have estimated installed capacity requirements to range from 4.5 MW to 15 MW (Ministry of Economic Development, 1977; B.C. Hydro Corporate Group, 1983).
Table VI.

Installed Energy Capacity Requirements Calculations

PRODUCTION SCENARIO 1: Anticipated Mine Life of 8 Years

:Total Tonnes Mined 41.0 x 10^6 tonnes

:Nominal Hourly Production Rate 41.0 x 10^6 tones = 585 tonnes/hour
8 x 365 x 24 hours

:Energy Requirements

Low Estimate Ore (25.21 kWh/tonne x 585 tonnes/hr) + Waste 1.4 (1.46 kWh/tonne x 585 tonnes/hr)
= 15944 kW

Allow for 85% Load Factor = 18758 kW or approx. 18.8 MW

High Estimate Ore (29.74 kWh/tonne x 585 tonnes/hr) + Waste 1.4 (3.14 kWh/tonne x 585 tonnes/hr)
= 19970 kW

Allow for 85% Load Factor = 23495 kW or approx. 23.5 MW
Table VII.

Installed Energy Capacity Requirements Calculations

PRODUCTION SCENARIO 2: Anticipated Mine Life of 20 Years

:Total Tonnes Mined  41.0 x 10^6 tonnes

:Nominal Hourly Production

Rate  41.0 x 10^6 tonnes = 234 tonnes/hour
20 x 365 x 24 hours

:Energy Requirements

Low Estimate  Ore (25.21 kWh/tonne x 234 tonnes/hr) +
Waste 1.4 (1.46 kWh/tonne x 234 tonnes/hr)
= 6377 kW

Allow for
85% Load Factor  = 7503 kW or approx. 7.5 MW

High Estimate  Ore (29.74 kWh/tonne x 234 tonnes/hr) +
Waste 1.4 (3.14 kWh/tonne x 234 tonnes/hr)
= 7988 kW

Allow for
85% Load Factor  = 9397 kW or approx. 9.4 MW
5.4 CONCLUSIONS:

The RED-CHRIS copper-gold deposit is selected for application of the preliminary methodology proposed in the previous chapter. The deposit, owned by Kidd Creek Mines Ltd. (60%), Norcen (20%), and Silver Standard Mines Ltd. (20%), is situated southeast of Iskut, and contains 41 million tonnes of mineralization grading 0.56% copper and 0.34 grams/tonne gold. The gross in-situ value of the deposit based on mid-June 1984 metal prices is approximately $631 million.

RED-CHRIS has not been developed to date chiefly because of low copper prices. Additional important constraints that have exacerbated this situation include insufficient or absent transportation and community facilities, lack of low-cost power, and potential environmental impacts.

Based on the assumption that the potential mine would operate for a period of 8 to 20 years, high and low gross energy demands were derived from energy consumption data in the literature. Production over 8 years would require installed capacity of within the range 18.8 to 23.5 Megawatts. Production over 20 years would require installed capacity of within the range 7.5 to 9.4 Megawatts. These estimates provide reasonable upper and lower bounds based on several simplifying assumptions and therefore provide an important basis for examining alternative energy supply options in the next chapter.
CHAPTER SIX

EVALUATION OF ENERGY SUPPLY ALTERNATIVES FOR RED-CHRIS

6.1. PURPOSE

The purpose of this chapter is to present a reconnaissance level evaluation of the energy supply alternatives available for potential development of the RED-CHRIS deposit. The evaluation is performed using the methodology proposed in Chapter 4 from the perspective of a mine planner.

In order to present the analysis in as concise form as possible, the results of extensive research into energy alternatives will be presented in summary form.

The chapter consists of three parts. Part One develops the Core Information Environment, while Part Two develops the Basic Evaluation Environment. Concluding the chapter is a unifying part that examines the influence of peripheral strategic data on the outcome of the analysis, and highlights those areas requiring further research.

6.2. CORE INFORMATION ENVIRONMENT

The Core Information Environment's primary purpose is to focus the energy supply issues pertaining to a particular deposit through a compilation of background and strategic data. This task is carried out in a format which responds to eight key questions concerning the problem environment.

Introductory background information on the status of
RED-CHRIS deposit's exploration and development was presented in the preceding chapter. It is understood that this information is vital to the Core Information Environment.

**Strategies Data Base Sets**

Three strategic data base sets are developed to supplement information on the deposit's status in order to focus the energy supply issue. The first identifies the key interest groups involved in the energy supply analysis and establishes their objective functions. The second investigates geological parameters and energy requirements of the deposit. The final strategic data base examines regional aspects of mineral development. These data bases must be kept current so that an understanding of the deposit's energy supply environment remains valid.

6.2.1. **Strategic Data Base One – Interest Groups and Objectives**

The analysis of energy supply alternatives must acknowledge and incorporate the influence of key identified interest groups if a public resource perspective is to be achieved and the implementation of decisions is to be successful. For RED-CHRIS we wish to know who effects the energy supply selection process, and who is affected by potential energy project implementation. Not all interests affected will be inclined to exert an effect on the selection process, and so an interest group profile must be made explicit.
if distribution and equity considerations are to be understood.

Groups identified as having key interests or responsibilities related to the energy project evaluation are structured into a three-part classification. Figure 6-1 schematically illustrates key relationships among these groups. Note that some members of Group C have interests in both subsets.

OBJECTIVE GROUP A: MINERAL DEPOSIT OWNERS

Kidd Creek Mines - 60% owner of RED-CHRIS
Norcen Energy - 20% owner of RED-CHRIS
Silver Standard Mines - 20% owner of RED-CHRIS

OBJECTIVE GROUP B: INTERESTS DIRECTLY OR INDIRECTLY AFFECTED BY THE PROJECT

Tahltan Nation - native residents of Iskut, Eddontenajon, aboriginal land claims and subsistence economy
Non-native residents - year-round and seasonal commercial operators, and labourers at Iskut, Eddontenajon, Tatogga Lake and Ealue Lake.
Non-residents - special interest groups concerned with tourism, wildlife, resource development anthropology, and energy policy.
OBJECTIVE GROUP A:
Mineral Deposit Owners

IMPACTS

CONTRAINTS
LOCAL SOCIAL AND ECONOMIC BENEFITS

OBJECTIVE GROUP B:
Interests Directly or Indirectly Affected by the Project

Diverse Social and Private Objectives And Issues Both Related and Unrelated to Project

OBJECTIVE GROUP C:
Subset 1: Social Energy Policy Interests
Subset 2: Government Administrative Interests

Figure 11. Schematic Illustration of Key Interactions Among Objective Groups
OBJECTIVE GROUP C: COLLECTIVE SOCIETAL INTERESTS

Subset One - Social Energy Policy Interests

Ministry of Energy, Mines, and Petroleum Resources - Public energy policy, energy project and review and regulation.
B.C. Hydro - Remote power planning, existing water reserves.

Ministry of Forests - Crown timber and access.
Ministry of Environment - Biophysical land use and impacts, waste monitoring and regulation, environmental rehabilitation.
Ministry of Transportation and Highways - Access, sand and gravel resource use.
Ministry of Finance - Taxation
Ministry of Industry and Small Business - Industrial and Private Investment and development, regional resource development.
Ministry of Tourism - Commercial facilities and Parks
Regional District of Kitimat/Stikine - Regional resource planning

Subset Two - Government Administrative Interests

Ministry of Lands, Parks, and Housing - Crown land use and access, Park protection.

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The foregoing diverse interest groups reflect a broad spectrum of public and private objectives. In order to reduce these to a manageable and understandable number, it will be necessary to identify the principal objective function for each group. Once the objective function is identified, key variables and mechanisms to achieve the objective, such as risk reduction strategies, can be discussed. In the following discussion, objective functions, variables, and achievement mechanisms are related to the process of choosing an energy supply alternative for the mining development.

OBJECTIVE GROUP A: Mineral Deposit Owners

Objective Function: Maximize net benefits from its mining investment. The general decision rule applicable to this objective function can be stated as follows:

\[
\text{maximize } \hat{\Pi} = P - \sum c_i
\]

where \( \hat{\Pi} \) = profit

\( P \) = gross benefits over project life equal to total revenue from the sale of the product plus plant salvage value

\( \sum c_i \) = sum of the set of costs including capital, labour, energy (fuel), materials, licences, and internalized social costs over the project life, such as required environmental control equipment and procedures, and possibly special environmental and social programs related to impacts exceeding the project life.

The objective function is maximized by choosing and
implementing an optimum combination of alternatives which produce the greatest expected value of a discounted stream of uncertain costs and benefits over the life of the project, using a corporate investment decision making rate of return.

While the delineation of the firm's objective function is, in itself, a relatively straightforward procedure, the planning process is made more complex by the necessity to accommodate elements of risk and uncertainty. Indeed, the firm's perception of risk and uncertainty, and its ability to isolate and develop management strategies can profoundly influence the alternatives chosen by the firm.

Three elements of risk that are particularly relevant to energy supply are now examined. The first concerns the tradeoff between the necessity to install costlier and better quality equipment, or incur larger operating costs, and the desire to attain a certain level of technological reliability. A decision on the desired level of technological reliability requires information on the probability of downtime and resultant lost revenues, as well as capital and operating costs of alternatives. Where the probability distribution of downtime is not well established, such as for new technologies, a strategy to manage this uncertainty might be to install standby generating capacity. Standby capital and operating costs must then be accounted for in the decision. The appropriate decision rule is to choose the alternative with the highest expected present value. This can be generalized as follows:
\[ a = E(R_a) - K_a - O_a \]
\[ b = E(R_b) - K_b - O_b \]

Where \( E(R) \) = expected present value of the revenue stream; \( K \) = capital cost; \( O \) is the present value of the stream of operating costs.

For example, if \( K_b > K_a \)
\[ O_b > O_a \]

\( E(R_a) < E(R_b) \) indicating lower expected revenue for alternative a because of lower expected technological reliability, and \( [(K_b + O_b) - (K_a + O_a)] < [(E(R_b) - E(R_a))] \) then \( I^a_b > I^a_a \) and the decision is to choose alternative two.

The second issue of risk concerns the tradeoff between incurring higher initial capital equipment costs and the desire to retain the option of improving the system performance or efficiency at some future date. The decision format for improvement flexibility is analogous to that of technological reliability. A decision to capitalize on the flexibility of an alternative and improve its efficiency, for example, requires information on capital costs, revised operating costs, salvage costs, as well as expected benefits of the improvement in terms of greater net revenue.

1 more formally this can be expressed as:

\[ I^a_a = E \sum_{i=1}^{n} \frac{R_{a_i}}{(1+r)^n} - K_a + \sum_{i=1}^{n} \frac{O_{a_i}}{(1+r)^n} \]
\[ I^a_b = E \sum_{i=1}^{n} \frac{R_{b_i}}{(1+r)^n} - K_b + \sum_{i=1}^{n} \frac{O_{b_i}}{(1+r)^n} \]
The risk associated with this tradeoff, represented by suboptimal project net present value, appears to be diminished with mining operations of relatively shorter duration because of more rigid constraints on overall project design.

Secondly, it is generally desirable to maximize the capacity factor of the energy supply alternative selected for the integrated mine/mill complex. Capacity factor is a measure, independent of technological reliability, of the service availability of the system. A high capacity factor (i.e., close to or equal to 100%) ensures minimum down time and therefore minimizes costs. If an energy supply alternative with a capacity factor less than 100% is to be considered, then the question that must be examined is whether the net present value of the integrated mining complex subject to an interruptible schedule, based on some known or estimated probability distribution of energy system downtime, can exceed the net present value of a similar complex reliant on an energy supply system capable of 100% capacity factor.

The third issue of risk contains two related components worth explicit mention. First, it is generally desirable, in order to minimize costs, to maximize capacity utilization. In mining this entails optimizing the operational aspects of the process of mining, the transport of ore to the mill, the milling circuit, the storage of concentrate and the disposal of waste. For example, as insurance against unanticipated downtime in mining due to weather, geological or labour factors, it may be desirable to consider installing mill
capacity lower than mining capacity. The intended result is to maintain mill operations at optimal levels, and to minimize revenue losses. As before, the operative decision rule is to select an optimum combination of processing designs that maximize net present value.

A final issue concerns anticipated energy costs and their impact on design and operation of the mining complex. As with most industrial plants and processes, there is a certain degree of flexibility in the choice of fuel. With energy costs becoming an increasingly large part of overall mining costs, however, one of the critical decisions affecting mine profitability is the choice of fuel and concomitant energy generation and use equipment. Although short-term fuel costs are generally unpredictable, it is highly probable that over the medium to long term both actual and relative fuel prices will change.

By combining energy technology capital costs with relative fuel price trends, one can derive the following three alternate decision scenarios:
Alternative One
Relatively more expensive
capital equipment or process
using relatively inflation
proof fuels

Alternative Two
Relatively less expensive
capital equipment or process
using relatively inflation
prone fuels

Alternative Three
Relatively expensive capital
equipment or process with
capability for interfuel
substitution

To determine the difference in estimated net present value of each alternative it is necessary to identify capital costs and an uncertain stream of costs associated with the choice of fuel and its predicted price path. Since prediction of future fuel prices is becoming increasingly difficult and complex, the firm's choice of fuel/generation/energy application combinations will be based on either formal and explicit assumptions about future relative fuel price trends, or informal expert judgement.

While estimation of future energy price trends will
always be subject to uncertainty, two techniques can aid in achieving a higher level of confidence in probability estimations of future trends and hence add confidence to relative estimates of net present value. The first technique involves constructing anticipatory scenarios and assigning respective probability ranges based on expert judgement. If, for example, the scenario deemed "most likely" entails a major shift in the relative prices of fuels, then additional initial investment in equipment capable of interfuel substitution may lead to lowest project costs on a present value basis. If more accurate data were to become available then formal modelling of price trends and timing could be incorporated into the net present value analysis of alternatives.

The second technique considers comparison of overlapping probability distributions of anticipated profits for each alternative, while focusing on known capital costs and uncertain future fuel costs as the dominant variables. Given that each alternative can be defined by its mean (Expected profit $\hat{E}(\Pi)$) and its variance (represented by a range of expected outcomes) and assuming similar Gaussian distributions, then the general decision rule would be to select the alternative with the highest mean expected outcome if the firm is risk neutral. If the firm's principal decision makers are risk averse or risk tolerant, then a more formalized analytical methodology must be employed to specify the tradeoff between mean and variance.

In summary it is evident that the firm's principal
objective of achieving maximum profit entails many complex interrelated decision strategies. Complexity is particularly evident when considering the relationship of energy supply inputs to the overall mining project. Strategies to reduce risk and manage uncertainty must be considered cautiously with full awareness of their probabilistic inputs. Nevertheless, these strategies can focus the number of decision criteria and therefore lead to more confident evaluations of net present value.

OBJECTIVE GROUP B: Interests Directly or Indirectly affected by the Project Objective Function: Maximize economic and social well-being and environmental integrity.

The general decision rule corresponding to this objective can be stated as:

$$\text{maximize } \sum_{t=0}^{T} b_t - \sum_{t=0}^{T} c_t$$

An energy project is favoured if it achieves the highest Net Present Value (NPV) of a discounted stream of measurable and imputed social, economic and environmental costs ($c_i$) and benefits ($b_i$) over the life of the project's effects (from $t=0$ to $T$), based on each group's rate of discount.

The decision rule differs from that of GROUP A by including additional benefits and costs such as those related to distributional equity and the impact of project externalities, which would not necessarily be considered in the decision making framework by the energy project proponent. The
objective function may be represented formally as
\[ f(e_i, s_i, w_i) \]
where
- \( e_i \) represents some direct measure of economic well-being such as income;
- \( s_i \) represents a group of socio-economic variables, including the maintenance and enhancement of community social vitality, cultural diversity, community autonomy, social services, political efficacy, native land rights, and the preservation of traditional culturally-related subsistence activities.
- \( w_i \) represents a set of environment-related variables such as the preservation of wildlife habitat and the ease of impact mitigation. A number of other important environment-related variables may be addressed as constraints or as variables to be minimized. In the latter case, a modification to the objective function would be required. In the former, the process of satisfying interest group desires could be stated as follows:
\[
\max (e_i, s_i) \text{ subject to } w_i < w^*_i
\]
where \( w^*_i \) represents maximum acceptable values for hydrological alteration, the fisheries impact, the level of undesirable effluents or emissions and the degree of irreversibility associated with an energy-related project.

Finally it should be noted that the maximization of direct economic benefits, \( e_i \), may be facilitated by the promotion of certain activities which lead to the diversification and stabilization of economic activity, the
establishment of local employment and training opportunities, the attraction of new service industries, and the increased purchase of local goods and services.

OBJECTIVE GROUP C: Collective Societal Interests

The third major objective function to be considered is that associated with society in general. It is the role of government, representing all diverse social interests both individually and in totality, to direct its efforts to maximize this overall objective function (also referred to as a social welfare function). Generally such a function may be formalized as

\[ w = f(E_i, P_i, S_i) \]

where \( E \) represents economic variables broadly defined to include all direct and imputed social costs and benefits.

\( P \) represents political considerations

\( S \) represents social issues such as distributional equity and environmental issues of risk.

With regard to the issue of energy supply for mining addressed in this study, there are two objective subsets in this function that are directly relevant.


The B.C. government listed the following elements in its 1980 Energy Policy Statement as being central to provincial energy policy:

(1) effective government organization
(2) industrial development based on extensive provincial resources
(3) reduced dependence on imported oil and increased use of natural gas, hydroelectricity and other B.C. produced energy resources
(4) expanded conservation efforts
(5) increased support of research and development in energy
(6) a streamlined project review process with "full consideration of social, environmental and ecological implications"
(7) protection of B.C.'s own energy needs in assessing proposed energy exports, and
(8) energy prices that encourage conservation and adequate energy development, but that also protect the needs of consumers

Items 2, 3, and 4 appear to be the most relevant to the issue of energy supply for mining development, at least in the short-term. The provincial government's attempts to encourage resource development using domestic energy resources priced at a level which encourages their efficient utilization are most aptly addressed by these three items.

There are various measures the government could employ to help achieve these policy goals. For example, it may be a worthwhile activity for government to jointly participate with private developers in surveying and carrying out a detailed quality assessment of domestic energy resources as a means of promoting their use, where there is a high probability that
imported petroleum-derived fuels would otherwise be used. In a situation such as this, a relatively small amount of public investment over a short-term might return a significantly greater amount of economic benefits over a much longer term.

OBJECTIVE SUBSET 2: Government Administrative Interests

Legislation enacted by the provincial government provides the legal authority and administrative framework for achieving broad government social and economic goals. In the context of a specific industrial project such as mining, the objective of government would be to maximize the effectiveness of government legislative authority, where

\[ NPV = \sum (b_i) - \sum (a_i) \]

where \( b_i \) = gross benefits to the public, such as lower social and environmental costs through the internalization of these costs by the firm, as well as resource rents, licences and taxation.

\( a_i \) = public costs of administering the appropriate legislation and regulations, and possibly, public financial assistance for project development, product marketing or diversification, once again to achieve longer term public goals.

Government legislation can therefore be viewed as a mechanism to achieve public goals. The overall public interest is best served when net present value (NPV) is maximized using a social rate of discount. The issues of risk inherent in ineffective government regulation of industrial projects are
potentially of the following two kinds.

In the first situation where government carries out little or no regulation, then the obvious short-term benefits of lower public administrative costs to government and higher project profitability for the firm may be offset in the longer term by potentially higher public costs pertaining to distributional equity of project impacts. For example, inadequately regulated effluent discharge may affect downstream fisheries thus incurring long-term public rehabilitation costs.

The second situation, over-regulation, is likely to entail unnecessary expenditure of public funds on deployment of manpower and resources for regulation with decreasing marginal gains in public welfare. Simultaneously, relatively higher costs imposed on the firm, perhaps in the form of taxation or environmental controls, may lead to a situation where mining operations and future options are severely constrained or perhaps curtailed. Once again social welfare is not maximized because of inefficient use of public and private resources.

6.2.2. **Strategic Data Base Two - Energy Demand**

Strategic Data Base Two identifies key factors which determine, and refine RED-CHRIS's potential electrical energy requirements. Two categories of information are examined: geological and physical development. The former concerns physical and mineralogical information, while the latter encompasses mining, milling and support facilities. Estimates will be of a reconnaissance nature in the absence of a
conceptual plan having been conceived for the deposit. Nevertheless, energy consumption trends can be suggested and information requirements can be outlined in areas where uncertain energy consumption may occur. Judicious reference to energy consumption data from existing mines is an integral part of this strategic data base.

Geological

RED-CHRIS is commonly referred to as a 'porphyry' deposit. This nomenclature identifies the deposit as having a style and origin of mineralization and host geology analogous to many of the world's large-tonnage, low-grade copper and molybdenum deposits found in Peru, Chile, the mid-western United States, and in the Highland Valley of B.C. (Sutherland Brown, 1976). This knowledge provides an important reference point from which to compare documented energy consumption at developed deposits.

The following information areas provide the geological basis needed for preliminary estimation of energy demand:

Mineralization - Occurs predominantly as chalcopyrite (CuFeS2) and pyrite (FeS2) as grains less than one millimetre, disseminated in argillic to sericitic altered intrusive rocks, or as blebs up to several millimetres in quartz-rich intrusive rocks and veinlets of quartz up to several centimetres wide. Subordinate mineralization includes magnetite (Fe3O4), hematite (Fe2O3), bornite (Cu5FeS4), molybdenite (MoS2), sphalerite (ZnS) and galena (PbS). Copper bearing minerals are very
weakly auriferous (gold bearing) and argentiferous (silver bearing). Economic mineralization grade tends to increase with a corresponding increase in quartz and hence rock hardness, an important factor to consider when calculating mining costs.

Deposit Configuration - Mineralization occurs in two discrete zones, referred to as the Main and East Zones. The Main Zone has dimensions of: 500 meters length; 150 meters width; and 0 to 200 meters depth below surface. The East Zone has dimensions of: 400 meters length; 80 to 100 meters width; and 0 to 300+ meters depth below surface. The two zones are elongate in a northeasterly direction, and are bounded on the southeast by a major fault.

Deposit Grade/Tonnage -
Total Deposit Drill Indicated "Reserves":
41 million tonnes of 0.56% copper and 0.34 gm/tonne gold
Main Zone Drill Indicated "Reserves":
34.38 million tonnes of 0.51% copper and 0.23 gm/tonne gold
East Zone Drill Indicated "Reserves":
6.62 million tonnes of 0.82% copper and 0.93 gm/tonne gold
Overall Stripping Ratio: 1.4:1.0
Cut-off Grade: 0.25% copper equivalent

Physical Development/Mining/Milling
Geological parameters indicate that the deposit would be amenable to open-pit mining methods with possible limited bulk underground mining.

The term physical development, as used here, encompasses
mining, milling, support infrastructure and logistics of an operating mine. Energy consumption estimates assignable to these activities and installations are normally conceived during the mine feasibility and conceptual planning stage. At the reconnaissance level, however, preliminary estimates can be advanced, and a framework for information requirements outlined. These data will assist with subsequent more detailed estimates.

Mining and milling concern the process of extracting mineralized rock from the ground, liberating and recovering the economic minerals by mechanical and chemical means, producing a metal concentrate, and disposing of waste materials. The mining and milling process anticipated for RED-CHRIS would be analogous to that of established mines. Figure 12 displays this process, the numbers in brackets refer to gross energy consumption data reported in Chapman and Roberts (1983) and Joe (1979).

Energy consumption is anticipated to be within the ranges displayed, except perhaps in the areas of transport, water and tailings handling, and heating. A harsh northern climate and mountainous terrain may provide an upward bias to energy consumption in those areas. Similarly, byproduct recovery, specifically gold, molybdenum, silver, zinc, and lead, energy input cannot be reasonably established without bulk metallurgical testing.
Figure 12. Mining and Milling Process and Energy Requirements
Note that the energy consumption data in Figure 12 represent gross energy requirements, of which electrical energy is only a portion. For example, crushing and grinding may be 90% electrical, flotation 30% electrical and product preparation 10% electrical (Kihlstedt, 1975).

Energy demands previously derived for RED-CHRIS, ranging from 7.5 to 23.5 MW installed capacity, also reflect gross requirements. These estimates are anticipated to be revised downwards as mining and milling engineering design proceeds.

Related mine support facilities and activities that would require an indeterminate electrical energy consumption include power plant operation and maintenance, power transmission losses for a remote power supply, and new or expanded community housing and service industries, including any non-related secondary industry that would be attracted to the mining community.

6.2.3. **Strategic Data Base Three - Regional Influences**

Strategic Data Base Three investigates answers to the question: what is the nature of peripheral influences on problem definition, and how are these influences likely to focus the problem?

Regional influences which potentially alter the energy supply environment for RED-CHRIS include: (a) development at nearby mineral deposits, (b) nearby non-mining industrial development, (c) transportation and infrastructure related to (a) and (b), and (d) settlement of native land claims. These
activities could influence relative changes in energy supply cost, location, scale, timing, and impact of energy alternatives and post-mining use of energy supply.

The following salient conclusions emerged from a review of the Ministry of Industry and Small Business Development's (1983) studies on Northwest Economic Development.

(a) Nearby mineral deposit development

Potential influence appears restricted to development at five deposits: Schaft Creek, Stikine Copper, Kutcho Creek, Eaglehead, and Klappan Coal, taking the form of:

- shared or consecutively used power supply. For example shared industrial development of More Creek hydroelectric site has been suggested to serve Schaft Creek, Stikine Copper and RED-CHRIS.

- shared experience and knowledge of local mining conditions at other deposits can lead to more cost-effective and energy efficient industrial processes and installations.

- Gulf Canada Resources plan to mine anthracite coal 80 kilometres southeast of RED-CHRIS beginning as early as 1986, may offer shared coal-fired electric generation possibilities.

(b) Nearby non-mining industrial development

Influence could occur in two areas:

- construction of all or part of the 2765 MW Stikine-Iskut hydroelectric proposal could provide a bulk regional power supply. Timing and anticipated cost of this power source could alter timing of mining development to take advantage of bulk low-cost power. In early 1984 B.C. Hydro
indefinitely deferred investigation of this project due to major surplus generating capacity in the Provincial system.

- expanded forest sector activity, (e.g., logging, sawmills, and pulpmills), could present similar power supply cost-sharing options as nearby mine developments. Logging road construction may provide access to potential small-hydro sites, or 'non-commercial' forests amenable to biomass-fired electric generation.

(c) Transportation and Infrastructure

Development in these two areas would proceed principally in response to mining developments. Benefits that RED-CHRIS could experience include lower costs for shipments of supplies such as diesel fuel, if diesel-fired generation were chosen, and expanded community and service sector demand for electricity. The latter could allow the mine to partially salvage power plant costs at the conclusion of mining operations if sufficient stable local reliance on this power supply had developed.

(d) Native Land Claims

Unresolved native land claim issues may exert potentially important social, environmental, and resource ownership/management influence on mineral development in the northwest. Nearly all of the present study area is encompassed by the Association of United Tahltans comprehensive land claim. Comprehensive claims concern traditional use and occupancy of the land and arise where government has not extinguished Indian interest through treaty arrangements (Ministry of Industry and
Small Business, 1983). The Tahltan claim has been accepted for resolution by the federal government of Canada, but cannot proceed until the provincial government agrees to become involved in claims negotiations.

The entire area surrounding RED-CHRIS is contained in the Tahltan comprehensive claim. The land presently supports a modest subsistence economy for the native community of Iskut, which otherwise experiences chronic high levels of wage-economy unemployment. Development of RED-CHRIS and its support infrastructure will certainly alter existing local subsistence activities with profound socio-economic effects on the local residents. In the absence of a comprehensive land claim settlement, the following areas of native concern will likely emerge as potential influences on RED-CHRIS's development:

- participation by Tahltan representatives in project planning
- demands by native and non-native residents for opportunities to participate in wage economy activities related to mine construction and operation
- restriction of mining and support activities from traditional fishing and hunting grounds
- guarantees of environmental mitigation where land, water, fisheries, and wildlife resources are altered or diminished in quality
- possible financial compensation
6.3. BASIC EVALUATION ENVIRONMENT

The purpose of the Basic Evaluation Environment is to perform the following analytical activities:

(a) Identify appropriate criteria corresponding to objectives identified for interest groups in the Core Information Environment.

(b) Conceptualize possible energy supply alternatives for RED-CHRIS.

(c) Develop a set of strategic data bases for each alternative which covers:
   (i) energy resource supply,
   (ii) energy conversion technology, economics and
   (iii) power generation-related regional environmental and social opportunities and risks, and
   (iv) other relevant information.

(d) Summarize analytical results in matrix form.

(e) Perform multi-criteria decision making analyses to indicate the most promising alternatives for advancement to the prefeasibility level of analysis.

6.3.1. Priority Valuative Criteria

Criteria are the operational measurements of objectives which allow the analyst to keep track of differences between alternatives in terms of their effects. Criteria measure the range, scale, and value of effects. Once determined, they can be synthesized by a variety of decision making techniques and the overall consequences and desirability of an alternative can
be evaluated. In this way it is possible to determine the degree to which an alternative satisfies the objective function of specific interest groups. Criteria which correspond to the objective functions of the four interest group categories of section 6.2.1 are outlined below.

OBJECTIVE GROUP A - Mineral Deposit Owners

Objective Function: The objective function to maximize net benefits (profits) from a mining investment is measured in monetary terms.

The variables which contribute to the general profit maximizing decision rule are also derived in monetary or imputed monetary terms. Two commonly used terms specific to energy projects can provide preliminary information on the magnitude of total costs. The first of these is a gross investment cost measure, dollars per kiloWatt of installed capacity ($/kW). This may be supplemented by annual operation and maintenance costs where available. The second is a measure of the annual energy cost and referred to as mills per kiloWatt hour (mills/kWh), a ratio of the average annual energy cost and the average annual energy produced.

The three issues of risk, involving tradeoffs between capital investment and technological reliability, improvement flexibility, and capacity utilization are ultimately represented in the decision rule as monetary measures perhaps within a probabilistic range. For a preliminary analysis where detailed cost data are generally not available, there are a number of useful indicators that can be used.
Technological reliability can be considered a function of low percentage downtime combined with high capacity factor.

Improved flexibility could be represented by the increase in efficiency of total operations and energy output as a function of capital input.

Capacity utilization, from the standpoint of power generation, could be represented by the percentage of annual energy demand of an industrial operation served by the principal generation system.

Finally, the indicators for uncertain fuel price trends can also be used to provide information for future profit maximization scenarios. Generally, fuel price data will include a base reference price and an anticipated time rate of increase (inflation factor). Probability ranges can be incorporated by suggesting a low, mid-range and high inflation factor.

OBJECTIVE GROUP B - Interests Directly or Indirectly Affected By the Project

Objective Function: The objective function to maximize economic and social well-being and environmental integrity is represented as a monetary value of net present value based on each group's discount rate. Measurements of distributinal equity and externalities may be assigned imputed monetary values through shadow pricing, willingness-to-pay, expert judgement or other techniques.

The three major variable sets in the objective function, economic, social, and environmental can be represented by a
A large number of criteria.

Economic well-being is commonly represented by increased income levels, number of employed, number and kind of new industries, and local expenditures.

Socio-economic variables are assessed in more abstract fashion. For example the objective to maintain a high level of community political efficacy may be assessed by the community's capability to perceive and effectively respond to external impacts. Similarly, a general criterion of community social vitality might be the level of participation in formal and informal collective community events.

Finally, environment-related variables are valued by criteria with both explicit and informal measures. For example, operational measures of habitat alteration may be represented by hectares of land, numbers and kind of species displaced, quantity of discharged effluent or emissions, and cost of mitigation programs. Less tangible environmental variables such as aesthetics or loss of wilderness can be indirectly measured by actions and economic activities of affected user groups.

OBJECTIVE GROUP C - Collective Societal Interests

Subset 1: Social Energy Policy Issues

Three elements of provincial energy policy are relevant to the study and can be examined for their criteria. The first policy element, promotion of industrial development based on extensive provincial (energy) resources, can be represented by the number, kind and economic contribution of new industries.
reliant solely on provincial energy, or as a rated function of industries partially reliant on indigenous energy.

The second policy element, reduced dependence on imported oil and increased use of provincially produced energy resources, can be measured by noting the relative cost change of imported energy commodities to domestic energy commodities and the resultant change (increase) in expenditures on domestic energy sources.

The final policy element, expanded conservation efforts can be valuated through the value of energy resources deferred for future use and the level of expenditures on conservation research, design, and construction.

Subset 2: Government Administrative Interests

Objective Function - The government objective of maximizing the effectiveness of project administration and regulation can be represented overall by a monetary value of net present value based on a social rate of discount.

The criteria that can be used to derive a measure of effectiveness include the cost of government regulation in both monetary and manpower terms and the costs of external project impacts assumed by the public and assumed by the project developer because of external social constraints.

In special cases where the public participates in energy resource development, then the net present value of the public's investment share must be indicated.
6.3.2. Energy Supply Alternatives

Uncertainty surrounding timing of RED-CHRIS mineral development, and the relationship of regional influences to the deposit's development, require the analyst to consider a wide variety of energy supply alternatives. For convenience these can be placed into one of the following four categories:

i) Commercially proven and with historic application to serving remote mineral development (e.g., diesel generation, small hydroelectric, and high voltage grid extension).

ii) Commercially proven but without historic mineral development application in remote areas (e.g., coal-fired generation, geothermal, biomass, peat, natural gas, combined diesel-small hydroelectric).

iii) Commercially doubtful, and without historic mineral development applications (e.g., solar, wind, biofuels).

iv) Unknown possibilities which may be encountered during the course of the analysis.

Conservation, cogeneration, waste heat recovery, and other specialized system arrangements and applications will not be discussed separately as they are generally subsets of the foregoing alternatives.

Summaries presented on the following pages for each power generation alternative are based primarily on literature reviews and where possible, communication with persons knowledgeable in small-scale applications.
6.3.2.A. Category I

i) Diesel Electric Generation:

a) Introduction

Diesel electric generation is presently the most widespread means of generating electric power at load centres in northern B.C. which are isolated from the provincial grid. Table III lists 27 known sites within the study area that rely on diesel fuel. End uses range from lodge operators to communities and operating mines. Installed capacities range from several tens of kilowatts up to 19 MW at Cassiar Asbestos Mines.

A sample of energy demands and costs (1982) experienced by several communities in the northwest are (Sigma Engineering Ltd., 1984):

<table>
<thead>
<tr>
<th>Community</th>
<th>Energy Demand (GW.h)</th>
<th>Cost (mills/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlin</td>
<td>2.38</td>
<td>162</td>
</tr>
<tr>
<td>Stewart</td>
<td>12.83</td>
<td>127</td>
</tr>
<tr>
<td>Telegraph Creek</td>
<td>1.01</td>
<td>158</td>
</tr>
</tbody>
</table>

Diesel's popularity stems largely from its well-proven reliability, flexibility, ease of transport and storage, easy and low-cost installation costs, and historic low fuel costs, along with a high energy content per volume. As a fuel resource, diesel has been readily available in the past and is likely to be for the foreseeable future. However there is a high probability that future prices will continue to increase at a higher rate relative to most other non-petroleum fuels.
In Canada, the nature of future diesel prices is complex and related to a number of factors including production levels of Canadian petroleum, development of Canadian oil sand deposits, availability of imports, and federal government oil-pricing strategies.

b) Technology

Diesel generation technology is well matured and few improvements can be anticipated. A conversion factor of 0.31 to 0.30 litres/kWh can be expected for installed capacities greater than 500 kW (Stilwell, 1980). The lifespan of meticulously maintained installations is not likely to exceed 20 years, hence longer mining operations will require replacement of original equipment.

c) Economics

The economic factors of diesel generation are well defined. Following is a general breakdown of capital, operating and maintenance costs after B.C. Hydro Corporate Group (1983). Installation and site costs will vary somewhat depending on the size and location of the facility.
Capital Costs

Engineering, design, site preparation, foundations, building and major equipment orders. - 40%
Equipment deliveries, installation, testing and commissioning - 60%

Annual Operating Costs

Fuel - 83%
Maintenance - 17%
- Labour - 64%
- Spare Parts and Materials - 25%
- Lubricating Oils - 11%

Salvage Value

= Years of serviceable life remaining × Replacement Cost

Plant Life

Annual energy costs of diesel are determined by the sum of the annual operating costs divided by the annual energy output expressed in mills/kWh. Since diesel fuel costs are a major portion of overall system costs. Real price escalations in future years will increase overall system energy costs. The economic attractiveness of inflation-prone diesel fuel will continue to be determined by the trade-off between capital and operating costs and the degree of certainty in future costs, and the attitudes towards risk of the plant owner.

Remote installations are generally sized to serve peak demand with standby units equivalent to 25-30% of installed capacity. Thus for RED-CHRIS under a 20 year mining life scenario with a peak demand capacity of 7.5 MW, an additional 2 to 2.5 MW installed capacity would be required.

For RED-CHRIS diesel generation, capital cost estimates
for installation and first year operating costs and energy costs can be reliably determined for production scenarios suggested in Section 5.2. In Appendix 3, Net Present Values are determined for diesel based on 8 and 12 per cent discount rates for high and low fuel price scenarios. The NPV of diesel for an eight year production scenario ranges from 82.7 to 146.6 million dollars, while the range of values for the twenty year production scenario is calculated as 48.1 to 115.1 million dollars.

d) Environment

The environmental problems associated with diesel-electric concern possible fuel spills during transport and handling, and land-use waste-heat and exhaust emissions in this remote environment are considered to be negligible. These problems can be largely ameliorated by careful site-planning, well monitored safety programs, and the use of waste-heat and process steam recovery for domestic uses (greenhouses and sewage), and industrial processes (steam, heating and metal concentrate drying applications). Experience with waste-heat recovery has proven particularly beneficial at the Polaris Mine on Little Cornwallis Island in the high Arctic (Nielson, 1984), and other locations (Pfeifer and Kovachevich, 1984; Hatsopoulos et al, 1978).

e) Social Implications

Social opportunities created by diesel generation are restricted to employment in the operation and maintenance of the system, and the transport of fuel.
f) Summary

To summarize, diesel generation has fulfilled the role of 'status quo' for remote electrical demands for many years. Its well-proven reliability, flexibility, and environmentally benign nature ensure its place in the future if the cost of diesel fuel, the major system expense, permits energy costs to remain competitive, when compared to alternative power generation systems, over the life of the mining project. Energy cost estimates prepared for RED-CHRIS in Appendix 2 indicate costs comparable to those experienced at existing remote northern sites.

ii) High Voltage Grid Extension:

a) Introduction

The feasibility of extending high voltage transmission lines from established grids to serve the energy requirements of northern mines has been investigated in a previous study by B.C. Hydro Corporate Group (1983). Their three alternatives and a fourth alternative proposed here, are examined in relation to their applicability to RED-CHRIS. They are displayed on Figure 6.

None of these alternatives is privately implementable from the standpoint of RED-CHRIS; most are large energy projects with power levels an order of magnitude greater than the history requirements. Nevertheless it is important to be aware of their potential influence in the regional energy supply picture.
Alternative 1:

Extending a 230 kV line from Telkwa or Skeena substation to serve Shaft Creek and Stikine Copper, with a 138 kV spur line run northeast to serve RED-CHRIS, and possibly Kutcho area mines.

Alternative 2:

Development of the Stikine/Iskut hydroelectric project, and subsequent construction of a 138 kV line from the nearest proposed substation to RED-CHRIS.

Alternative 3:

Development of More Creek hydroelectric project on a stand alone basis (Stikine/Iskut deferred or cancelled), with a 138 kV line from the powerhouse to RED-CHRIS.

Alternative 4:

Extending a 230 kV line south from the Yukon to serve Midway, Cassiar, McDame, Kutcho Creek and Stikine area mines, step down to 138 kV, or 69 kV to serve RED-CHRIS from nearest distribution substation.

b) Alternative 1:

A 230 kV line from Telkwa substation would tap the existing provincial grid managed by B.C. Hydro. The 360 kilometre line would follow approximately along the Highway 37 corridor to a substation at Bob Quinn, from where lines would radiate to Stikine Copper, Shaft Creek and RED-CHRIS. An 80 kilometre line would be required to access the last.

B.C. Hydro's 1982 cost estimate for the lines to Stikine
Copper and Schaft Creek inflated at 10% p.a. indicate a cost of $230,000 to $321,000/km. for the 230 kV line, or about $83 million to $116 million to Bob Quinn. Sigma Engineering Ltd. (1984) data indicate a further cost of $7.7 million for the 80 kilometre 138 kV line to RED-CHRIS.

The average industrial rate cost of power over the next decade at Telkwa is forecast to be at a slightly higher than 2.5c/kWh in constant 1982$ (B.C. Hydro Corporate Group, 1983). Therefore, if one assumes a transmission power loss of 10%, the 7 year and 20 year production schedules at RED-CHRIS would incur annual energy expenditures of approximately $4.1 million and $1.8 million.

The practicability of this alternative to RED-CHRIS is clearly a function of several factors which must be overcome nearly a decade (estimated project lead time 7 to 10 years) before power would be required:

- Approval of the project under the B.C. Utilities Commission Energy Project Review Process.
- Commitment by B.C. Hydro to meeting the mining development power requirements.
- Development of all three deposits with a common time frame in order to share costs.
- Sharing of capital costs under a staged mine development scenario.
- Mitigation of uncertain environmental and social impacts (e.g., Native Land claims).
Engineering design of geotechnical (terrain, foundation, climate) factors related to route selection and cost.

c) Alternative 2

Alternative 2 is premised on the completion of the Stikine/Iskut mega-hydroelectric project proposed by B.C. Hydro. The 2800 MW project would generate nearly 13000 GW.h yearly and as recently as 1980 was scheduled for an in-service date of 1991 (B.C. Hydro, 1980). In 1982 this date was revised to 1994, and in 1984 the project was deferred indefinitely (B.C. Hydro, 1982).

B.C. Hydro Corporate Group (1983) has calculated the average energy cost to RED-CHRIS if the mine were to proceed at the time of hydro in service dates between 1995 and 2000. The average energy cost was determined as 65 mills/kWh at 8% discount rate, to 90 mills/kWh at 12%.

Considering the nature of the uncertainties surrounding this project, and that it is not a private option available to RED-CHRIS, this alternative will not be reviewed further.

d) Alternative 3

Development of the More Creek hydroelectric project (the smallest component of Stikine/Iskut) some 80 kilometres south of RED-CHRIS, has been proposed irrespective of Stikine/Iskut status. The project would have an installed capacity of 155 MW and provide a firm 600 GW.h energy annually. This would be sufficient to serve the requirements of Stikine Copper, Schaft
Creek and RED-CHRIS provided a 50 MW diesel standby generator were installed for critical water periods.

The More Creek hydroelectric project could be constructed in 5 years at a cost of about $305 million (1984$) and supply energy at an average annual cost of 60 - 79 mills/kWh (1982 mills), excluding interest during construction and the cost of transmission to mine sites (B.C. Hydro Corporate Group, 1983). Transmission to RED-CHRIS is estimated to cost an additional $6.4 million. Therefore total average annual energy costs for RED-CHRIS could be expected to approach the range of 80 - 100 mills/kWh (1984 mills).

Technical aspects of the proposal involve a 135 meter high earthfill or concrete arch dam impounding 1300 million m$^3$ of storage covering 4100 hectares. A 37 meter high dam constructed on upper Forrest Kerr Creek would divert this creek water into the upper part of the reservoir. Few insurmountable technical constraints are envisaged for a 22 meter wide corridor for 138 kV transmission to RED-CHRIS.

Preliminary assessment by Ministry of Energy, Mines and Petroleum Resources, and Ministry of Environment (1983) determined that impacts could occur in the following areas:

- altered stream and sediment flows in the Stikine River delta.

- loss of More Creek valley as an access option to Schaft Creek minesite.

- loss or diminished heritage resources, wildlife habitat, water quality alteration, and visual corridor impact
adjacent to Kinaskan Lake Park depending on route selection of transmission lines. Impact on Native Land claims is also certain.

- transmission to RED-CHRIS would provide the opportunity to substitute hydroelectric power for subsidized diesel generation at Eddontenajon.

In summary, the main factors requiring clarification before this option can be considered more seriously include:

- A commitment of B.C. Hydro to pursue More Creek project independently of the Stikine/Iskut system.

- Timing of the Stikine Copper, Shaft Creek and RED-CHRIS mine start-ups.

- Effect on transmission construction costs of various route selection options and social/environmental conditions for which amelioration and mitigation may be required.

e) Alternative 4

A 230 kV transmission line connected to a Yukon grid is proposed as a future option for serving power requirements of northern B.C. mines. The proposal stems from consideration of the following:

- If large scale mining or aluminum smelting (Thompson, 1981) are to proceed at some future date in the Yukon, they will require large power installations. Surplus power may be available on a firm or temporary/interruptible basis.

- Depending on the nature and location of power generation (i.e., hydroelectric v. natural gas-fired) and
transmission grids, power may be within economic transmission distance of northern B.C.

- Transmission distances south to some northern B.C. deposits (e.g., Midway, Cassiar area, Kutcho area) are shorter than comparable grid extensions from the B.C. grid at Telkwa, and equidistant for other deposits (e.g., Stikine Copper, Shaft Creek and RED-CHRIS).

The principal issues that would require clarification in order to further consider the viability of this proposal include:

- Patterns of industrial growth and power supply in the Yukon.

- Transboundary provincial/territorial energy transfer policy.

- The issue of who pays? and how much?, which is partially dependent on mine start-up dates.

- The estimated average energy cost to individual mines such as RED-CHRIS.

- The nature of social and environmental impacts.

iii) Small Hydropower:

a) Introduction

Small hydropower is defined as a hydroelectric project with installed capacity of less than 20 MW in accordance with the regulation guidelines of the B.C. Utilities Commission Act. Small hydropower would thus be potentially exempted from review under the Energy Project Review Process.
Small hydropower has experienced a modest revival over the last 10 years in North America (Broad, 1978). The revival commenced in the northeastern U.S. as an attempt to seek out lower cost means of generating electricity in an oil-dependent industrial economy, and has spread westward and north into Canada for similar reasons of economics and environmental impact of alternatives (Willer and Alden, 1979; Lawrence, 1979; Wilier, 1978; Engebretson, 1978; Alward et al, 1979). Indeed, small hydropower has been vigorously advocated as conforming to the ideals of soft-energy path popularized by Lovins (1978) and Brooks and Paehlke (1980).

The small hydropower resource in B.C. was investigated by several recent studies (Crippen Consultants, 1980a, b; Sigma Engineering Ltd., 1984a, b). Special emphasis was placed in these studies on the application of small hydro to serving the needs of remote load centres which are currently served largely by diesel electric generation. Additionally, in a more focused study, B.C. Hydro Corporate Group (1983) undertook a preliminary examination of several potential small hydropower sites to serve proposed mines in the northwest. These B.C. studies along with other recent work reported in Energy, Mines and Resources Canada (1983) and Gladwell and Warnick (1978) furnish an excellent base of information and guidelines for reconnaissance assessment of small hydropower as an energy alternative for RED-CHRIS.

Before an examination of this alternative's application to RED-CHRIS is presented, a brief review is carried out of
common technologic, economic and environmental features.

b) Technology

Technology for small hydropower was well developed nearly 50 years ago. Since then, improvements have been in the area of standardized materials, efficiency, and the use of microprocessor flow optimization and equipment protection (Mayo, 1979; Sigma Engineering Ltd., 1984a; Department of Environment, 1982). Operational efficiencies currently achieve over 80%, and system life expectancies of over 30 years are common. The scope for dramatic technologic improvement in forthcoming years is therefore restricted.

The principal components of a small hydropower system which facilitate the conversion of moving water into electricity include: water intake, penstock to transmit water to powerhouse, turbine linked to a generator to convert water pressure into electrical energy, a transformer to boost the low voltage to minimize power loss during transmission, and a step-down transformer to reduce transmission voltage to a useable level (Sigma Engineering Ltd., 1984a). Highly competitive specialization by component manufacturers permits maximum flexibility in choice of system design to harness almost every conceivable hydrological environment.

c) Economics

The economics of small hydropower are examined in a number of recent studies (Engebretson, 1978; Williamson, 1978; Chen, 1978; Stilwell, 1980; Crippen Consultants, 1980a, b; Sigma Engineering Ltd., 1984a, b). The principal factors
affecting economic viability which were cited include capital costs of plant, capital costs of transmission and access roads, operation and maintenance costs, management costs, transmission downtime costs which may include alternate energy costs, water rent and licences, environmental costs such as fishways and habitat improvement, and energy costs of the next best alternative. Non-linear cost relationships exist between many of the foregoing components under various hydrologic conditions.

Inflation is manifest mainly in the escalation of annual operation and maintenance costs and taxes. Operation and maintenance costs are typically in the range 0.5 - 1.5% of capital costs. Taxes in B.C. include a water licence of $.05/kW, water rent of $2.50/thousand kWh, school tax and income tax. Economic viability is therefore primarily dependent on capital cost financing and, to a lesser extent, existing taxation rates.

Preliminary cost estimates for proposed small hydropower projects in B.C. are derived in the Sigma Engineering Ltd. (1984a,b), Crippen Consultants (1980) and B.C. Hydro Corporate Group (1983) studies.

Sigma Engineering Ltd., identified 13 sites in northwestern B.C. with installed capacities ranging from 320 kW to 10,300 kW (mean=1,616 kW). Energy costs were forecast to range from 32 to 100 mills/kWh (mean=59 mills/kWh). Substantially higher costs were forecast by B.C. Hydro Corporate Group (1983) for 7 potential small hydro sites.
Table VIII.
Data For Proposed Small Hydropower Sites
Shown in Appendix Two

| SITE | DRAINAGE AREA (km²) | DESIGN FLOW (m³/s) | FRAC.¹ | HEAD (m) | I.ELEV (m) | P.LEN (km) | ACCESS (km) | T.LINE (kV) | INST. CAP (MW) | EST. ANNUAL POWER (GW.h) |
|------|---------------------|-------------------|--------|----------|-----------|-----------|-------------|-------------|--------------|-----------------|--------------------------|
| 1. Unnamed Creek² | 88 | 1.76 | 0.45 | 100 | 3600 | 3.5 | 60 | 1.2 | 4.7 |
| 2. TODAGIN CREEK³ | 320 (est) | 6.5 | 0.5 | 110 | 5000 | 5.0 | 60 | 5.0 | 21.9 |
| 3. Unnamed Creek A | 92 | 1.84 | 0.45 | 106 | 4200 | 7.0 | 60 | 2.3 | 17.4 |
| | B | 81 | 1.63 | 0.45 | 106 | 4500 | 7.0 | 60 | 2.1 |
| 4. MAITLAND CREEK | 200 | 4.0 | 0.45 | 121 | 3800 | 26.0 | 138 | 3.4 | 14.8 |
| 5. McEwan Creek⁴ | 162 | 3.24 | 0.45 | 106 | 4200 | 1.0 | 60 | 2.4 | 9.5 |
| 6. BURRAGE CREEK | 580 | 33.64 | 0.50 | 136 | 1600 | 1.0 | 230 | 32.0 | 140.3 |
| 7. LITTLE ISKUT RIVER | 366 | 21.2 | 0.50 | 61 | 7000 | 7.0 | 138 | 9.1 | 39.7 |

FRAC. FIRM - Fraction of annual flow which can be considered to be firm
HEAD - Net vertical distance in metres between intake and turbine
I.ELEV - Elevation at intake
P.LEN - Penstock length in metres
ACCESS - Length of new access required to powerhouse from HWY 37 or BCR subgrade
T.LINE (kV) - Transmission line rating in kilovolts, and distance of line to mine
INST. CAP - Installed capacity in megawatts (kW x 1000) for 100% design flow
EST. ANNUAL POWER (GW.h) - Estimated annual power output in gigawatt hours (kWh x 10⁶) base on fraction of flow estimated to be firm

¹Sites 1-5 referenced to Klappan Gauge 08C0001 = 0.02 m³/s/km²; Sites 2, 6, 7 referenced to More Creek Gauge 08C0005 = 0.058 m³/s/km²
²B.C. Hydro proposal estimated installed capacity as 2 MW. B.C. Hydro Corporate Group (1983)
³B.C. Hydro proposal. Ibid.
⁴McEwan Creek marks the northern boundary of Spatsizi Park, the proposal is outside the park
⁵Proposal includes a dam 400 metres wide and 140 metres high; power output calculated on run-of-river
designed to serve 7 potential mines in the northwest. Average annual energy costs ranged from 90 mills/kWh at Adanac for a storage system utilizing Surprise Lake, to 175 mills/kWh for two small run-of-the-river installations to supply 7 MW peak demand to RED-CHRIS. Both estimates used an 8% discount rate.

Further to the south, studies in Washington State and Oregon State by Engebretson (1978) and Kaufman et al., (1980) reported energy costs at recent installations as ranging from 29 mills/kWh to 68 mills/kWh for units of 500 kW to 85 MW. These costs are biased downwards owing to lower transportation costs, shorter transmission distances, and federal and state financial assistance programs. Clearly, energy costs can vary widely depending on site specific hydrology and terrain features, and assumptions used in financial models.

d) Environment

Environmental considerations for small hydropower fall into two categories: those caused by the project and those which may alter the integrity of the project. Since most small installations are run-of-the-river, impacts occur primarily in the stream course between the diversion intake and the powerhouse tailrace (Green, 1980; Woodworth, 1978). Impacts include reduced water flows and altered temperature for aquatic resources, altered sediment load transport and possible reduction in aesthetic appeal. In steep gradient remote northern streams these impacts may be difficult to distinguish from those caused by annual stream flow variations. Greater impacts are likely to be associated with transmission line and
access routing. These activities can result in timber and wildlife habitat losses, and increased public access to sensitive terrains.

Small hydropower projects which use dams and storage in lakes would potentially cause additional impacts on shoreline aquatic and recreational resources. In the northwest, special attention may be necessary to minimize potentially negative impacts on native food fisheries.

The integrity of small hydropower projects may be altered by such watershed activities as logging, mineral exploration, and associated access construction.

e) Social Implications

Social benefits to the public arising from the implementation of small hydropower arise largely from the use of a renewable energy source which reduces the nation's dependence on non-renewable and imported petroleum-based fuels. Relatively few jobs are created outside the construction phase and periodic plant and transmission maintenance.

f) Resource Supply

Hydrology and terrain conditions in the area surrounding RED-CHRIS appear favourable for consideration of small hydropower. A combination of moderate precipitation, abundant streams with gradients greater than 10 degrees and head potentials exceeding 100 meters are common within 50 kilometres of the deposit.

Seven sites within 50 kilometres transmission distance are identified in Appendix 2. Table VIII lists the main
parameters of each site.

With the exception of Site 6 on Burrage Creek, all sites are proposed as run-of-the-river, no impoundments are proposed. Burrage Creek site would involve construction of a 140 meter high dam, 400 meters wide at its crest, in a narrow, steep walled gorge approximately 2 kilometres above Highway 37. A preliminary airphoto analysis indicates the area to be underlain by steeply dipping sedimentary rocks mantled by sand and gravel deposits. 380 hectares would be inundated at a mean reservoir elevation of 820 meters.

A detailed analysis was not performed to determine reservoir volumes and hence its contribution to yearly energy output is uncertain. The run-of-the-river calculations in Table VIII can therefore be viewed as conservative.

Todagin River site is in a basin where energy output can most likely be enhanced by low-cost outflow regulation of Kluea and Todagin Lakes.

All sites proposed are tributaries of the Stikine or Iskut Rivers, and typically exhibit large annual streamflow variations. Peak flows occur from May through August, an additional peak of short duration commonly occurs in October. December to March are typified by very low flows dominated by ice conditions.

Figure 13 shows a typical hydrograph for the region. Without provision for storage, the maximum flow that could be utilized, irrespective of increased installed capacity, would be that represented by the lowest flow period in March,
Figure 13. Klappan River Hydrograph 1962-1979
Sta No. 08CC001
typically only a few cubic meters per second. Clearly, power outputs can be measurably enhanced by utilizing natural lake storage or creating a reservoir to reallocate peak summer flows to winter months, which coincide with heaviest power demands.

The increased benefits presented by storage would have to be weighed against corresponding capital cost and environmental costs which would tend to reduce overall economic attractiveness.

6.3.2.B. **Category II**

i) Coal-Fired Thermal-Electric Generation

a) Introduction

Coal-fired thermal-electric generation as an energy supply alternative is briefly examined from the point of view of two generation scales and two generation technologies.

The generation scenarios examined are: a large (> 100 MW) coal-fired generation plant at Mt. Klappan which serves the Mt. Klappan coal mine and other regional needs, and generation designed solely to meet the needs of RED-CHRIS.

The two principal generation combustion technologies examined are: conventional combustion and fluidized bed combustion. Coal gasification technology is very experimental at this stage and will not be considered.

These discussions are preceded by an examination of the availability of thermal coal for electric generation in the northwest.
b) Resource Supply

Thermal coal is currently mined in northeast B.C. near the townsite of Tumbler Ridge and exported to Japan via rail transport through Prince Rupert. The substandard and incomplete B.C.R. rail spur to the northwest could be upgraded and technically permit the transport of thermal coal to the region. However this option cannot be seriously considered in the short-term.

Coal resources are known to occur in the study area at three locations as shown in Figure 2-7 (Dolmage, Campbell and Associates, 1975).

Location 1 - Lignitic coal occurs in sporadically explored seams up to 0.3 meters thick in a northwest trending basin measuring 17 kilometres by 5 kilometres which straddles the Rapid River 10 kilometres above its confluence with the Dease River and approximately 50 kilometres east of Cassiar (Dolmage, Campbell and Associates, 1975). No reserve and quality data are available from this deposit.

Location 2 - Lignitic coal occurs in five known locations in the Tuya River drainage and one location in the Tahltan River drainage approximately 40 kilometres northeast of Telegraph Creek. Coal exposed in seams up to 10 meters thick in canyon walls returned calorific values of 20,230 kJ/kg (9680 BTU/lb) for the Tuya River occurences and 13542 kJ/kg (6480 BTU/lb) for the Tahltan River occurence. PetroCanada is currently exploring these deposits (B.C. Hydro Corporate Group, 1983).
Location 3 - Low volatile bituminous to anthracite coal occurs over an area of nearly 3800 km² in an area known as the Groundhog Coalfield at the headwaters of the Nass, Skeena, Spatsizi and Klappan Rivers. Past attempts to develop these extensive coal measures have been stymied by the area's remoteness and structural complexity of coal seams.

Presently, Gulf Canada Resources work at Mt. Klappan some 80 kilometres southeast of RED-CHRIS has outlined an anthracite deposit which they estimate contains inferred reserves of over 890 million tonnes in 12 seams averaging 0.5 to 5.5 meters thick (Western Miner, 1984). Gulf Canada Resources is proceeding to develop the deposit for surface mining at an annual output of 1.0 to 5.0 million tonnes for export to Asian and European markets. Coal-fired thermal electric generation to supply the Mt. Klappan Mine's estimated 280 GW.h annual energy requirements is currently one of three power options under investigation (B.C. Hydro Corporate Group, 1983; Western Miner, 1984; L. Sivertson, personal communication).

By all accounts, the Groundhog coal deposits, and the Mt. Klappan anthracite deposits in particular warrant closer examination as a coal-based energy supply source for RED-CHRIS.

c) Technology

Two methods of coal combustion can be considered to facilitate this requirement.

Conventional coal-combustion involves introducing finely milled coal mixed with air into a suspension where combustion occurs at high temperatures. The technology is well-proven and
has been extensively used in plants of several hundred MW. While this system offers flexibility in its use of coals with differing thermal quality, expensive grading and sizing quality control is necessary (MacGregor et al, 1976). Typical conversion efficiencies attained in the process are in the range of 30-40%. The principal drawbacks of this technology relate to emissions of fly ash, sulphur dioxide, nitrogen oxides, carbon dioxide and thermal and trace element-contaminated cooling waters.

Fluidized bed combustion involves combustion of granular coal particles in a turbulent bed composed of at least 99% inert particles comprised of coal ash, and lesser limestone and dolomite. The bed is kept in a fluid state by the upward motion of air which may be pressurized. The fluidized bed permits high heat release and heat transfer rates. The addition of limestone or dolomite as sulphur absorbent and the relatively low combustion temperatures below ash-particle fusion point permit up to 90% removal of sulphur oxides and suppressed nitrogen oxide emissions. In addition, a wide range of coal qualities can be burned (Markowsky and Wickstrom, 1979; Coal Processing Consultants, 1978). Pressurized fluidized bed combustion (PFBC) can occur in small boiler sizes (installed capacity of several 10's of MW) at efficiency levels approaching 50%. Thus advantages are offered over conventional combustion in small-scale applications.

The principal problems with PFBC technology concern premature materials corrosion, sulphur and nitrogen oxide and
carbon dioxide emissions, and disposal of trace elements (mercury, arsenic, flourine and bromine) concentrated in spent bed material (Hoy et al, 1979; Davidson and Moore, 1979; Fennelly et al, 1977; Department of Environment, 1982).

It should be noted that this technology is still largely in the experimental stages. B.C. Hydro has investigated the application of PFBC to Hat Creek thermal coal but few data are available.

d) Economics

The first alternative, a large coal-fired plant to serve Mt. Klappan coal mine and other regional needs, was examined by B.C. Hydro Corporate Group (1983) in their power supply study for the North West Economic Development Task Force. Under conditions of assured thermal coal supply, the study was able to derive economic costs of coal plant installation. Using experience elsewhere in western Canada, where costs of installation are reported at $1220 to $3000/kW (1982$), the present value of capital costs per kW with a 10% discount rate at Klappan Coal ranged from $674 to $2006/kW (1982$).

Assuming that individual mines pay for the capital costs incurred to supply electricity requirements, then the costs attributed to RED-CHRIS under different production scenarios can be determined.

At $1220/kW and 8% discount rate, capital costs for the two production scenarios suggested for RED-CHRIS would be $6.85 x 10^6 (20 year mine life) and $17.17 x 10^6 (8 year mine life). At $3000/kW and 12% discount rate, capital costs would be $16.6
x 10^6 (20 year mine life) and $41.6 \times 10^6 (8 \text{ year mine life}).

Using mid-range capital costs ($2000/kW) B.C. Hydro calculated average annual energy costs at RED-CHRIS to be in the range of 91 to 116 mills/kWh (1984$).

B.C. Hydro's analysis was based on employment of conventional combustion technology. Preliminary analysis by researchers elsewhere indicate that large scale PFBC may be less costly by virtue of higher fuel efficiencies, lower environmental costs, and more cost-effective design (Kennedy et al., 1979; Corman, 1979).

Alternative two, coal-fired generation at Mt. Klappan solely for RED-CHRIS, can only be considered if: (a) it out-competes other alternatives, and (b) the Mt. Klappan mine utilized electricity other than coal-fired thermal electric or grid extensions.

A small coal-fired plant to serve the needs of RED-CHRIS would most certainly consider PFBC because of efficiency and cost advantages at smaller scales. Fuel costs are anticipated to be high, although substantially less than diesel generation fuel costs. For example, if one assumes year round operation at 40% efficiency, with semi-anthracite coal with an average heat value of 29,600 kJ/kg (13,500 BTU/lb) and a plant heat rate of 11,400 kJ/kWh, then 18.8 and 7.5 MW plants would annually consume 54,470 tonnes and 21,786 tonnes of coal. At $91/tonne coal (1984$, inflated B.C. Hydro derived mine-head cost), this consumption represents annual fuel costs in the first year (1984) of $4.96 million and $1.98 million for a mine
life of 8 and 20 years respectively or an equivalent of about 35 mills/kWh contribution to energy costs.

The capital costs of these small coal-fired plants are unknown, however they most certainly would be higher than the B.C. Hydro estimates for larger plants.

e) Environment

Environmental impacts attributed to coal-fired power generation will be additional to those created by Gulf Canada Resources Mt. Klappan coal mine. The general nature of environmental impacts related to this technology has been investigated by Coal Processing Consultants (1978) and Henschel, (1978). The principal areas of concern which are likely to emerge include the following:

- Industrial land use and landscape alterations are anticipated to occur adjacent to Spatsizi and Tatlatui Wilderness Parks.
- Wildlife habitat (particularly for moose) will be temporarily and in some cases permanently displaced.
- Some guide outfitting and river rafting/touring activity along the Klappan system may be displaced.
- Increased hunting pressures will occur from new access and worker recreational demands.
- Careful siting of spent fuel bed materials will be necessary to avoid leaching of potentially concentrated trace elements into major river systems which support resident and anadromous fish populations.
- Air emissions containing sulphur and nitrogen oxides
will drift over adjacent parks with the prevailing winds and potentially cause acidification of precipitation.

f) Social Implications

Social issues which are likely to emerge from these projects include:

- Native land claims.
- Emissions, land use and aesthetic impact on Spatsizi and Tatlatui Parks.
- Community location, access, housing and level of services.
- Opportunities such as employment, education and health care which may become available to the local populace.

ii) Geothermal:

a) Introduction

Geothermal energy is the earth's natural heat. It is generally diffuse near the surface of the crust but is concentrated occasionally under favourable geologic conditions.

Mountainous areas in western Canada typified by high relief, high levels of precipitation and groundwater recharge, and relatively young geological environments with high thermal gradients are ideal environments for deep circulation of meteoric waters, and hence have given rise to major geothermal fluid systems (Souther and Halstead, 1973; Geothermal Resources Council, 1980).

Surface manifestations of geothermal energy commonly occur as hot mineral springs, geysers, or other water and
vapour emanations, although the relationship is not equivocal. Thermal fluids typically contain high levels of dissolved solids, a function of the depth and composition of the rock and heat regime through which these waters were circulated. Knowledge of fluid composition aids geoscientists in their understanding of subsurface geology and reservoir characteristics, and allows an interpretation of energy potential and possible future environmental difficulties.

The exploitation of geothermal energy to provide electricity and industrial or domestic heat applications has been carried out successfully in Lardarello, Italy; Iceland; Wairaki, New Zealand; and The Geysers in California. The Geysers, with an installed capacity of over 900 MW in 1980, are projected to eventually provide 2000 MW for the city of San Francisco (National Academy of Science, 1979; Nevin, Sadlier-Brown Goodbrand Ltd., 1981).

Geothermal energy is contained in six types of reservoirs: hot water, natural steam, geopressurized, normal heat gradient, hot dry rock, and molten magma. Only the first two categories have proven economically viable and technically feasible to date. Energy contained in the remaining four is either too diffuse or technically inaccessible at present.

Hot water reservoirs are created when meteoric water circulates through permeable crustal rocks, rises by convection, and is trapped by an overlying relatively impermeable formation (National Academy of Sciences, 1979; Peck, 1972). Water from the top and sides of the reservoir
cools and descends, where it regains heat and once again rises. Along the way, minerals are dissolved to form a dilute brine. Minerals generally consist of silica, sodium, potassium chloride, bicarbonate, sulphate, and borate (Peck, 1972). Occasionally radionuclides or heavy metals are present in trace amounts (Swain et al, 1980). The trapped nature of these waters often results in superheated temperatures and, consequently, greatly accentuated salinity levels. This presents technical problems in the areas of equipment corrosion, equipment fouling leading to lower efficiencies and environmental air and water emissions.

When the water is tapped it is permitted to rise in a borehole, resulting in a pressure drop, causing spontaneous vaporisation or 'flashing' to steam, followed by decrease in temperature. The fluid may be allowed to flash several times, each time the wet steam is bled off, removed of condensates, and allowed to pass through turbines to generate electricity. The residual brine may be re-injected, or not, or passed through a heat-exchanger where a 'clean' fluid is heated and utilized for domestic or industrial heating purposes. Because the temperatures are low, overall efficiencies are also low when compared to other forms of electricity generation. Typical efficiencies range from 10-20% (United Nations, 1978, p. 74) compared to 30-35% for a conventional coal-fired plant. Attempts to raise efficiencies and extend useful reservoir life have led to alternate modes of production using pressurized downhole pumps or 'binary-cycle' heat-exchangers. The latter
use low-temperature boiling fluids such as freon which are less damaging to power equipment.

Natural steam reservoirs are less common than hot-water systems. The environment of formation is essentially similar to the hot water one described above, however, as a result of low hydrostatic pressures, the water boils in the reservoir and a steam pocket develops near the top. The boiling process leaves behind most of the dissolved solids and thus tapped steam is usually tainted only by hydrogen sulphide, carbon dioxide, ammonia, and traces of boron. Steam is passed through turbines, after which it is condensed and cooled in forced draft towers prior to being re-injected (Riva and Mielke, 1978, p. 22). 'Waste heat' may find its way to local heating applications. The technology to extract electrical energy from natural steam reservoirs is quite advanced, the best example of current use is the large Geysers geothermal field in California. Where geothermal steam exists, it is a particularly desirable, economic, and environmentally innocuous energy resource.

Having thus introduced geothermal energy, what potential contribution to energy supply at RED-CHRIS can this form of power generation provide?

b) Resource Supply

Geothermal resource supply, economics, environmental and institutional factors were examined for B.C. in an extensive study by Nevin Sadlier-Brown Goodbrand (1981) for the Conservation and Technology Division of B.C.'s Ministry of
Energy, Mines and Petroleum Resources. A review of this study allows an assessment to be made of geothermal energy as a potential energy source for RED-CHRIS.

Definition of geothermal resources in B.C. is in its infancy. Nevertheless, based on interpretations of the distribution of young volcanic rocks, regional structures, and known thermal springs, it is possible to identify regions of high probability of geothermal energy occurrence. One such area, Meager Creek some 55 kilometres northwest of Pemberton in southern B.C. has been the focus of geothermal exploration for over 10 years, and the site of a recent attempt to install a 55 MW pilot plant (Fairbank et al, 1979; Reid, Crowther, and Partners, 1979; Reader, 1982; B.C. Hydro et al, 1981).

Northwest B.C. contains a major zone of moderate probability for geothermal resources of high temperature, and two smaller zones of high probability for high temperature geothermal (Figure 6). The high probability areas encompass the Mt. Edziza complex and lower Stikine and Iskut Rivers.

Mt. Edziza Provincial Park encompasses nearly all of the high probability zone. Surrounding areas are of somewhat lower potential. Despite an amended Geothermal Resources Act which permits private development of this resource, the Park Act specifically prohibits the activity in all Parks by virtue of Sec. 5(3) which states:

No natural resource except fish and wildlife taken . . . In a park of Class A . . . shall be granted, sold, removed, destroyed, damaged, disturbed or exploited except as authorized by a valid and subsisting Park Use Permit, which shall not be issued.
Table IX.
Summary of Geothermal Energy Costs From 50 MW Plants on Three Model Fields

<table>
<thead>
<tr>
<th>Case (Basis is Quality of Reservoir)(^1)</th>
<th>Available Wellhead Energy (kJ/kg)</th>
<th>Number of Wells Required; Total well Cost ($millions)(^2)</th>
<th>Generating Plant Type; Capital Cost ($millions)</th>
<th>Total Capital Costs ($); Total Capital Costs ($millions)(^3)</th>
<th>Levelized Total Energy Costs (in mills/kWh)(^4); a utility’s discount rate of:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Dry Steam</td>
<td>880</td>
<td>7</td>
<td>direct</td>
<td>1 400</td>
<td>18.3, 23.7, 32.4</td>
</tr>
<tr>
<td>100% steam</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Wet Steam</td>
<td>305</td>
<td>17</td>
<td>flashed-steam</td>
<td>1 900</td>
<td>24.8, 31.8, 43.4</td>
</tr>
<tr>
<td>20-35% steam</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Hot Water</td>
<td>150</td>
<td>40</td>
<td>binary</td>
<td>3 200</td>
<td>41.8, 53.2, 71.8</td>
</tr>
<tr>
<td>0% steam</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^1\)The dry steam reservoir is at 240°C and is analogous to the Geyers, California; Case 2 is analogous to Roosevelt, Utah, and is at 270°C (despite the higher temperature it has lower heat content); Case 3 is analogous to East Mesa, California, and is at 180°C.

\(^2\)Includes production, reinjection (waste disposal), and spare wells.

\(^3\)Costs other than well field and plant are included, viz. $10 million capitalized exploration, gathering system, 75 km transmission lines, etc.

\(^4\)Operating, maintenance and administration costs are included; one component is redrilling wells after 15-year life; life of plant is 30 years, 1991-2015; capacity factor is 80%.

unless, in the opinion of the Minister, issuance is necessary to the preservation or maintenance of the recreational values of the Park involved.

and furthermore in Sec. 18(e) neither shall any person "establish or carry on any commercial or industrial activity or enterprise in a Park."

The second area of high temperature, high probability is located nearly 160 kilometres southwest of RED-CHRIS. The intervening terrain and climatic conditions preclude consideration of its feasibility at this time. Remaining therefore are lower probability areas flanking and north of Mt. Edziza. Within these areas, the only 'window' that appears to exist for geothermal electric utilization for RED-CHRIS appears to be if a high temperature, high probability area were newly discovered in a zone formerly considered to be low probability. Discovery of such a field would need to occur many years prior to mine start-up to allow for adequate exploration and development.

c) Economics

The opportunity for geothermal utilization appears restricted. Nevertheless, from a strategic data base perspective, it is worthwhile to review geothermal energy costs in the event a potential field is discovered. Nevin Sadlier-Brown Goodbrand (1981) have determined energy costs for hypothetical geothermal plants with 50 MW and 1500 kW installed capacity. Table IX summarizes reservoir conditions and energy costs for the 50 MW plant under private development.

The uncertainties likely to be encountered during
geothermal exploration and development in remote and inaccessible northwestern B.C. would entail a high level of expenditures and suggest that energy costs would be high relative to other forms of energy production.

d) Summary

To summarize, geothermal energy utilization for electrical generation is a technically well-proven, and flexible energy resource dependent on a relatively "inflation proof" "fuel". Northwestern B.C. contains a broad zone of moderate probability for high temperature geothermal resources adjacent to high temperature, high probability resources contained within Mt. Edziza Provincial Park. The status of resource knowledge in the northwest warrants close monitoring to establish when it may become feasible for individual mine owners to explore for and develop geothermal energy at an acceptable level of risk.

iii) Biomass:

a) Introduction

Forest biomass has proven to be an enduring and renewable source of inexpensive energy especially suited for local economies. Its decline as a primary fuel in Canada from 12% in 1945 to 2% in 1969 (Biswas, 1974) has now been reversed with the progressive rise in the price of petroleum based fuels. Forest biomass is now a growing competitor as a primary source for liquid hydrocarbon feedstock, feedstock for process heat, electricity generation, and steam.
b) Resource Supply

Examination of forest biomass as a primary fuel source for electricity generation for RED-CHRIS involves a complex consideration of factors such as resource supply, imposition of new widespread logging activity in the remote northwest, social and environmental concerns arising from this logging activity, ownership and management of the forest resource, as well as examination of the technological and economic factors pertaining to the power generation. Figure 14 illustrates the major processes from a standing wood resource through power generation.

Raw biomass is a bulky commodity. It is most cost-effectively used if transportation distances, and hence costs, are minimized. A prime requisite for the assessment of biomass power generation viability is thus an availability of adequate uncommitted biomass.

RED-CHRIS is located central to the proposed Stikine and Klappan Public Sustained Yield Units (PSYU) (although actual timber management designation may have changed, i.e., now part of Cassiar Timber Supply Area (T.S.A.), the data presented here are still valid). Stikine and Klappan PSYU'S encompass combined areas of 3,852,000 hectares of productive forest land containing 106,953,000 m$^3$ (110 m$^3$/ha) of merchantable coniferous timber greater than 18 centimetres diameter at breast height and 10 centimetres at the top. The total net recoverable annual allowable cut is 887,300 m$^3$ per year on

Figure 14. Biomass Fired Power Generation - Processes and Energy Flows
good, medium, and poor sites (Forestal International Ltd., 1980). No estimate is available for total biomass per hectare, which would include decadent, non-commercial and deciduous volumes.

The forest resource is presently uncommitted to harvesting except for several small local timber sales for local uses. RED-CHRIS therefore appears ideally situated to consider biomass as a power generation alternative.

c) Technology

Biomass is combusted either directly, in a fluidized bed state or using a gasifier/turbine system. The technology is well established and reliable (Energy, Mines and Resources, 1978). For example, in 1978 B.C. pulp and paper mills generated about 33% of their electricity requirements from 'waste' hog fuel, a trend which is forecast to increase (Hiballer Forest Magazine, 1981).

Commercial applications of conventional and fluidized bed combustion are capable of combusting a wide range of feedstock qualities, often with high moisture contents. Total biomass harvesting is therefore more easily accommodated. Energy Products of Idaho Ltd. have successfully employed fluidized bed technology to combust fuel, sized less than 8 centimetres, containing up to 65% moisture and variable amounts of mineral matter (Levelton and Associates, 1978).

d) Economics

Economic analysis of wood-based energy conversion systems can be broken down into two components: economics of wood supply
Table X.

**Biomass-Fired Power Generation Cost Estimates From Recent Studies**

<table>
<thead>
<tr>
<th>PLANT SIZE (MW)</th>
<th>CAPITAL COST $ x 10^6</th>
<th>COST/INST. kW</th>
<th>OPERATION &amp; MNTNCE mills/kWh</th>
<th>ENERGY COST $1.24 x 10^6</th>
<th>LOGGING COST $1.24 x 10^6</th>
<th>REFERENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>(70.9)</td>
<td>($1417/kW)</td>
<td>(79.4)</td>
<td>($1.24 x 10^6)</td>
<td>(70.9)</td>
<td>A</td>
</tr>
<tr>
<td>37.6-49.5</td>
<td>(53-62)</td>
<td>(1240-1417)</td>
<td>(24-30.7)</td>
<td>19.9</td>
<td>(35.3)</td>
<td>B</td>
</tr>
<tr>
<td>25</td>
<td>(26.2)</td>
<td>($1047/kW)</td>
<td>(70.6)</td>
<td>n/a</td>
<td>(70.6)</td>
<td>C</td>
</tr>
<tr>
<td>14</td>
<td>(37)</td>
<td>(2642)</td>
<td>(69.2)</td>
<td>n/a</td>
<td>(69.2)</td>
<td>D</td>
</tr>
</tbody>
</table>

1. Reported data has been escalated by 10% p.a. to 1984$ and shown in ().
2. Hog fuel available locally at virtually no cost
3. U.S.$ converted to CDN$ at rate of 1.3

B) B.C. Wood Waste Energy Coordinating Committee, (1978) Quesnel Hog Fuel Study
D) Acres Shawinigan Ltd, (1979)
and harvesting activity, and power plant economics. Estimates for the former are the least precise because of fewer fixed costs and the unknown relationships between terrain, climate, access constraints, stand variability and decadence in the local area. Several recent detailed cost estimates for biomass-fired generating plants are presented in Table X.

Capital costs for a biomass-fired plant can be calculated very roughly for RED-CHRIS based on these data more precise net present value calculations are presented in Appendix 3. A site factor of 1.5 is employed to allow for the area's remoteness and anticipated higher costs. Using the range of costs for the smaller power plants, and an operation and maintenance factor of 5% of capital costs, the following cost estimates would apply to RED-CHRIS:

Scenario 1 - 7.5 MW
Capital Costs - $11.8 to $29.8 million
O & M Costs - $0.6 to $1.5 million

Scenario 2 - 18.8 MW
Capital Costs - $29.5 to $74.7 million
O & M Costs - $1.5 to $3.7 million

Biomass fuel costs can be determined for the Stikine and Klappan PSYU's from Forestal International Ltd.'s (1981) data for logging the Stikine/Iskut proposed hydroelectric impoundments. Logging costs are estimated at $13.60 per cubic meter, (1981$) or $18.10 per cubic meter (1984$), based on 10% annual inflation.

Volume requirements are determined using conversion data
from Burgess, (1978) and Energy, Mines and Resources Canada (1978). 6200 tons of air-dried wood per year are needed to produce 1 MW year of power. Since 6200 tons of air-dried wood are equivalent to 17,050 green cubic meters of wood, 7.5 MW and 18.8 MW plants would consume approximately 128,000 m$^3$ and 321,000 m$^3$ annually. Annual fuel costs would amount to $2.3 million and $5.8 million in 1984$.

A cost which is not included here is the opportunity cost to the public of not using the biomass for lumber, paper or other products if the timber is accessible and merchantable. If a net opportunity cost is foregone to the public by power generation from biomass, then stumpage fees may be an appropriate vehicle for the government to recapture this loss. The cost of alternative fuels and the value of mining to society would have to be considered as well. The absence of government policy in this area suggests further research to determine these economic relationships.

e) Environment

Environmental impacts related to biomass energy conversion must be examined from two aspects: harvesting and combustion. Harvesting produces land impacts not unlike those for commercial clearcut logging. However, reforestation of an area where total biomass harvesting has occurred, may create a landscape of greater aesthetic appeal because of more uniform 'greening up'.

Other environmental impacts would likely result from increased public access into previously remote areas.
Pollution, increased erosion potential, fire risk, modified wildlife habitats, and altered water quality may be other issues.

Conversion facilities also generate environmental impacts. The primary concerns are related to air emissions, ash disposal, land use, and disposal of cooling waters. Thermal losses can be minimized by waste heat recovery, and air emissions are generally of little concern since wood lacks the undesirable sulphur compounds found in coal and petroleum fuels (Rose and Olson, 1979).

Land use requirements for a conversion facility are likely to be minimal. The Hearst study in Ontario (1980), for example, estimated only 2.5 hectares would be required for its 14 MW plant. The land use demands of harvesting can be roughly calculated from forest inventory data if one assumes the PSYU volumes to be evenly distributed over the PSYU area. Thus a 7.5 MW and 18.8 MW plant consuming 128,000 m$^3$ and 321,000 m$^3$ annually would require logging of 1164 hectares and 2918 hectares. It is notable that the volumes represent 14.4% and 36.2% of the net annual allowable cut if only merchantable coniferous timber were used. The use of other timber would tend to overestimate both the land use and AAC fractions.

Nutrient loss cited as a potential environmental problem by Carlisle (1976) is not anticipated to be a problem for RED-CHRIS because harvesting would not exceed one rotation.

Positive environmental benefits may result from creating new moose habitat and forage.
f) Social Implications

The social impacts of a biomass alternative will differ from most other energy alternatives since harvesting and transportation of biomass are labour intensive occupations compared to hydroelectric and diesel-electric generation for example. The biomass alternative would allow local people to expand their skills from a subsistence-dominated lifestyle, and eventually diversify the local economy through local-based forestry activity.

Clearly, there are many complex social issues implied by this form of power generation which are deserving of further study.

iv) Natural Gas:

a) Introduction and Discussion

Natural gas is extracted from extensive deposits in northeast B.C. and subsequently distributed for domestic power generation and space heating, and sold to foreign markets.

The study area does not contain any natural gas deposits, nor is the regional geology conducive to the entrapment of natural gas deposits. Consideration of natural gas as feedstock for electricity production for RED-CHRIS would necessitate transport of gas into the region. Technically this might be accomplished in one of two ways:

- Construction of a small diameter pipeline from Pacific Northern Gas's line 450 kilometres to the south, perhaps along the Highway 37 corridor.
Construction of a small diameter pipeline from the Alaska Highway Pipeline some 300 kilometres to the north in the Yukon, either south along the Highway 37 corridor, or generally southeast across the Kawdy Plateau.

Natural gas is used to generate electricity in a manner similar to diesel; capital costs are therefore comparable. Natural gas is a cleaner fuel than diesel from an emissions standpoint, however efficiencies are in the same range of 32%-34% (John Wong, pers comm, B.C. Hydro).

Serious consideration of natural gas as an energy alternative for RED-CHRIS means that a number of preconditions would have to be satisfied. The following preconditions and comments apply:

- Surplus natural gas would have to be available from either northern or southern pipeline. Until recently Pacific Northern Gas has had surplus capacity although the implementation of a number of proposed LNG or petrochemical plants in the Prince Rupert or Kitimat area would alter this situation.

- Pipeline costs are subject to well-defined economies of scale related to the exponential increase in volumes of gas transportable with an increase in pipeline diameter. The unit costs of a small diameter pipeline built to serve RED-CHRIS are expected to be exceedingly high. Difficult terrain would be a major constraint to construction.

Teck Corporation has recently investigated the feasibility of constructing a natural gas pipeline on their
Schaft Creek deposit some 80 kilometres southwest of RED-CHRIS. The results of their analysis are unknown.

- The environmental, social policy and technical aspects of pipeline construction are anticipated to be more demanding and costlier than a transmission line transporting comparable amounts of energy.

- The pipeline life expectancy would outlast mine development, so that a likely precondition for construction might be the identification of future customers.

- Once a pipeline is in place, the sunk costs effectively nullify the opportunity for interfuel substitution. Careful supply/demand and price forecasts would be necessary.

b) Summary

In conclusion, it appears that natural gas as an energy source for RED-CHRIS would be subject to major areas of uncertainty and high 'front-end' costs which are likely to compromise its economic attractiveness considering the relatively short duration of mining operations. From an environmental policy standpoint the use of an abundant indigenous source is certainly desirable, however there are offsetting environmental and social concerns related to land use and construction. The possibility of sharing pipeline costs among several potential mines in the northwest certainly deserves further investigation.
6.3.2.C. **Category III**

i) Solar

a) Introduction and Technology

Solar electric power is produced by direct conversion of solar energy to electricity in photovoltaic cells. Photovoltaic cells are arranged in flat, curved stationary or directional arrays connected to storage batteries and load regulating systems for specific applications. An ideal solar cell array has a high power output per unit weight (watts/kg) and low cost per unit power output ($/peak watt) (Rauschenbach, 1980). Silicon cells are the most widely used thus far because of low material cost, higher efficiencies, low maintenance and little direct pollution (Council on Environmental Quality, 1978). Typical efficiencies for all types, notwithstanding greater semiconductor purity, range from less than 5% to about 13%, although experimental efficiencies up to 50% have been reported (Electric Power Research Institute, 1978).

b) Economics

An analysis of cost trends reveals a marked decline from the late 1950's to late 1970's in terms of installation costs per kilowatt of output. During this period, costs had declined from about $200,000/kW to less than $2000/kW by the early 1980's (Hayes, 1978; Bailey, 1980; Wiggins, 1978). Most estimates are derived for ideal insolation conditions based on optimum capacity factors: less than ideal conditions with low capacity factors will naturally result in higher costs.

As an example, a study carried out by Wiggins for the
Alberta Energy and Natural Resources found that for solar collectors positioned at Fort Smith (60 degrees north compared to 57.5 degrees north for RED-CHRIS) and Suffield (50.2 degrees north with high annual solar radiation) the actual annual utilization of peak power ranged from 14.3% to 17.8% respectively. Thus the actual costs of solar electric energy will be significantly higher for northern Canadian applications than prevailing estimates in the literature based largely on southern U.S. applications.

c) Resource Supply

Climatic data for the study area is incomplete. The best available data are for recording stations at Telegraph Creek and Dease Lake. Intermittent observations are available for Kinaskan Lake, 20 kilometres south, with two continuous record periods: during 1967 to 1970, and 1976 to 1977 (Meteorological Branch Records, 1967-1980).

The local climate can be characterized as generally cool to warm and moist during the short summer, with cold somewhat drier, long winters.

The distribution of precipitation and cloud cover is largely dependent on the interaction of rugged local terrain and the direction from which influencing air masses originate. As a general rule, higher elevations receive greater precipitation and cloud cover, whilst lower elevation valleys are less subject to the vagaries of diurnal cloud cover. This is reflected in an appropriate local comment which states, "It never rains at Kinaskan Lake."
Cockshutt (1980) has estimated light annual solar insolation as approximately 120 watts/m². Because of the high latitude, the amount of solar radiation in the winter is significantly reduced, coinciding with peak demands for power. The technology of large capacity storage battery systems is not sufficiently advanced to provide the type of storage levels that would be required by RED-CHRIS under these types of severe conditions.

d) Summary

In summary, at the present time the technology appears to have limited application to meeting RED-CHRIS potential base-load power requirements. Solar's principal contribution will be restricted to passive solar gain afforded by buildings sited as to take advantage of southern aspects. As the technology improves, and storage capabilities improve, solar may make a contribution to power requirements during long summer days.

ii) Wind

a) Introduction

Wind is a product of solar energy that is constantly renewed at the surface of the earth because of the uneven distribution of solar energy in the atmosphere. Wind has been termed a "non-polluting, non-depleting, safe solar energy source" (Mayer, 1981). The power contained in wind increases as the cube of wind velocity, therefore identifying areas which sustain high average annual wind velocities is necessary for investigating the potential economic conversion of latent wind energy into kinetic energy to produce high quality electrical energy.

The historical development of wind energy conversion systems (WECS) occurred over 1300 years ago in Persia, where a vertical axis windmill was invented to grind grain (Hunt, 1981). Harnessing wind declined in popularity with the advent of steam powered systems in the late 1800's, but during the last decade has experienced a modest revival in interest as a result of high petroleum prices.

A survey of recent literature has revealed a pervasive trend towards reinvestment in this technology with the result that wind energy conversion systems can now be considered on a competitive basis with conventional forms of energy conversion (Franklin Institute, 1978; DeRenzo, 1979; McCaull, 1973; Council on Environmental Quality, 1978; Wiggins, 1978; Haack, 1977; Hunt, 1981, Department of Environment, 1982; Miller, 1978).
b) Economics

An economic assessment of WECS cost trends by the Franklin Institute in 1978 concluded that optimum economies of scale occurred for units in the 1 to 3 MW range. An important consideration in their analysis is the cost-size relationship. Simply put, as the diameter of the blade is doubled, the area of wind intercepted quadruples. Cost decreases with increasing size to a certain point, after which costs escalate because structural difficulties arising from large stresses necessitate costlier engineering.

Few reliable cost data are available for large MW sized systems. The U.S. Department of Energy sponsored, cost-effective designed MOD-2 unit, rated at 2.0 to 2.5 MW output at wind velocities of 8.6 m/second, can provide very rough capital and energy cost comparisons for RED-CHRIS. The machine is a two-bladed large horizontal axis downwind teetered hub machine with rotor blade diameter of 91.4 meters. Cost of electricity is based on production of the 100th turbine. Capital costs per unit are reported as $3.54 million (U.S.$) in 1981, or about $6.1 million (Cdn$ - 1984).

Allowing for a site factor of 1.5 for costs for RED-CHRIS, a 7.5 MW and 18.8 MW system of WECS would cost a minimum of $18.3 million and $55 million respectively, assuming constant peak output (i.e., 100% capacity factor). The cost does not include storage, transmission, or an energy back-up system for periods of low wind velocities, or operation and maintenance costs. Fuel costs are nonexistent for a completely
WECS based system.

c) Resource Supply

For RED-CHRIS, the nature of local winds must be evaluated so that a measure of the economic viability of WECS may be assessed. Local wind data are virtually nonexistent. Portelli (1977) has compiled and summarized regional data in a study to help define air pollution climatology for Canada. His findings support those of an earlier study by Shaw et al (1972) who found that "generally speaking, persistent light winds (lasting 24-47 hours or longer) occurred most frequently in B.C., Yukon, and Alberta." Portelli further points out that lowest mean wind speeds occur in winter when a large "typically stagnant continental air mass" sits over northern areas. Mean seasonal wind speeds for maximum afternoon mixing heights are tabulated below. The maximum (afternoon) mixing height is a function of warm or cold air advection caused generally by daily heat inputs (Portelli, 1977, p. 2).

Table XI.
Mean Wind Velocities for Afternoon Mixing Layer

Northwestern British Columbia

<table>
<thead>
<tr>
<th>Season</th>
<th>Wind Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td>6 m/sec</td>
</tr>
<tr>
<td>Summer</td>
<td>&lt;5 m/sec</td>
</tr>
<tr>
<td>Autumn</td>
<td>5-6 m/sec</td>
</tr>
<tr>
<td>Winter</td>
<td>5 m/sec</td>
</tr>
<tr>
<td>Annual</td>
<td>5 m/sec</td>
</tr>
</tbody>
</table>
These values must be considered with reservation because of the profound effect that rugged terrain can have on local wind regimes. Kendrew and Kerr (1955, p. 43) observe that the strongest and most persistent winds occur in valley bottoms for the northern part of the province, but that moderate variability can occur over short distances. Wegley et al (1978) elaborate further by concluding that local terrain variations such as gorges, passes, and ridgetops often enhance local winds by accelerating and constricting air masses.

A descriptive, ecological-based wind-speed rating scale, the Griggs-Putnam Index, uses deformed coniferous trees as a basis for estimating annual wind speeds (see Wegley et al, 1978, pp. 5.28-5.33). As the wind velocity increases from 5 m/sec to 12.5 m/sec, trees show a tendency to become more deformed because branches grow preferentially to leeward in the zone of lowest energy.

The above considerations plus the writers' experience and informal field observations during several summers throughout the study area indicate that areas of significantly higher and more persistent than average annual wind levels probably occur near RED-CHRIS. However, as much of the terrain in the immediate area is at or above tree line, the influence of other variables such as snow cover and ice storms must be considered as biasing influences when making interpretations based on vegetation wind indicators.

Two areas in particular are suggested as worthy of investigation for wind potential evaluation (see Figure 6).
The first of these is Mt. Ehachezetle, about 10 kilometres northwest of RED-CHRIS and southeast of Iskut. The second location is on an unnamed ridge immediately east of the north end of Kinaskan Lake. Mt. Ehachezetle rises to over 2000 meters as an isolated massif bounded by major valleys on its southeast and west sides, and is renowned for its characteristically highly variable weather conditions. The ridge near the north end of Kinaskan Lake appears to help funnel winds down the lake and thus experiences moderate wind velocities near its peak throughout much of the day, as evidenced by considerably deformed trees.

d) Environment

In order to identify more clearly the environmental issues that pertain to WECS, an ERDA/NASA-Battelle Columbus Laboratory's study was carried out on the potential environmental impacts of a 100 kW experimental wind turbine at Sandusky Ohio (DeRenzo, 1979, p. 325-335). Their results show that the environmental impacts outside of minimal land-use alienation are largely restricted to alteration of the immediate micro-climate and potential impacts on resident or migratory birds.

Near RED-CHRIS, the potential sites which appear favourable at first blush are at or above treeline and hence few conflicts would arise regarding displacement of productive forest or wildlife habitat. Migratory bird route impacts are expected to be so low as to be negligible but would require further research.
The greatest land-use impacts would probably occur when providing for transmission corridors and access routes. These types of linear development would have impacts similar to transmission corridors from other site-specific forms of electricity generation except for locational differences. Route selection impacts cannot be evaluated here as they are dependent on WECS site selection. Overall, the lack of airborne, liquid, or solid emissions make this form of energy highly desirable from an environmental perspective.

6.3.3. Interpretation and Selection of Alternatives

The final task of the Basic Evaluation Environment concerns the interpretation, ranking and selection of most favourable alternatives. This will be conducted from the perspective of the mine planner who attempts to maximize the company's objective function, subject to external government and private interest constraints. It is most important to note that the evaluation could also be carried out from the perspective of one of the other three previously identified objective groups. The mine planner perspective is chosen because it can most easily be dealt with utilizing the present data available to this study. Tables XII and XIII have characterized the alternatives from the perspective of the mine planner. Table XII lists the quantitative and qualitative parameters pertaining to the firm's objective function variables, and examines the values and parameters for risk reduction criteria. Table XIII lists qualitative and
Table XII.
Characterization of Alternatives

<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>CATEGORY I</th>
<th>GRID EXTENSION</th>
<th>CATEGORY II</th>
<th>ENERGY ALTERNATIVES</th>
<th>CATEGORY III</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DIESEL</td>
<td>SMALL HYDRO</td>
<td>COAL</td>
<td>GEOTHERMAL</td>
<td>BIOMASS</td>
</tr>
<tr>
<td>Objective Function Variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Commercial Availability</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>2. Anticipated Project Lead Time (years)</td>
<td>2</td>
<td>2-4</td>
<td>5-7</td>
<td>2-4</td>
<td>7-10</td>
</tr>
<tr>
<td>4. Anticipated Energy Cost Range (mills/kWh)</td>
<td>175-185</td>
<td>32-175+</td>
<td>&gt;100</td>
<td>90-116+</td>
<td>43-96+</td>
</tr>
<tr>
<td>Risk Reduction Criteria</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Technical Reliability</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Moderate-High</td>
<td>Moderate-High</td>
</tr>
<tr>
<td>6. Technical Improvement Flexibility</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Moderate-High</td>
<td>Moderate</td>
</tr>
<tr>
<td>7. Capacity Utilization Factor (F)</td>
<td>95-100</td>
<td>&gt;80</td>
<td>95-100</td>
<td>60-100?</td>
<td>&gt;90</td>
</tr>
<tr>
<td>8. Probable Fuel Price Inflation Rate</td>
<td>Moderate-High</td>
<td>Low</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Low</td>
</tr>
</tbody>
</table>

n.a. - data insufficient to permit reasonable estimation
### Table XIII.

**Socio-economic, Environmental, and Political Characterization of Alternatives**

<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>CATEGORY I</th>
<th>ENERGY ALTERNATIVES</th>
<th>CATEGORY II</th>
<th>CATEGORY III</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DIESEL</td>
<td>SMALL HYDRO</td>
<td>GRID EXTENSION</td>
<td>COAL</td>
</tr>
<tr>
<td>Socio-Economic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Potential for new industry created or attracted</td>
<td>None</td>
<td>Minor</td>
<td>Major</td>
<td>Minor</td>
</tr>
<tr>
<td>2. Potential impact on subsistence economies</td>
<td>Low</td>
<td>Low-Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>3. Expenditures on local goods and services</td>
<td>Minor</td>
<td>Minor</td>
<td>Minor</td>
<td>Minor</td>
</tr>
<tr>
<td>4. Potential for employment opportunities: construction/operation</td>
<td>Minor</td>
<td>Moderate/Minor</td>
<td>Major/Minor</td>
<td>Moderate/Major</td>
</tr>
<tr>
<td>5. Possible overall impact on local income levels</td>
<td>Low</td>
<td>Low</td>
<td>Moderate</td>
<td>Low-Moderate</td>
</tr>
<tr>
<td>6. Potential impact on local native land claim options</td>
<td>None</td>
<td>Minor-Moderate</td>
<td>Moderate</td>
<td>Moderate-Moderate-High</td>
</tr>
<tr>
<td>7. Possible degree of local community political response</td>
<td>V.Low</td>
<td>Moderate-High</td>
<td>High</td>
<td>Moderate-High</td>
</tr>
</tbody>
</table>

<p>| Environmental Variables |                       |                     |                 |                 |            |         |        |       |      |
| 8. Land area required | Small | Small-Moderate | Large | Large | Moderate | Large | Moderate | Moderate? | Small? |
| 9. Water Volume Required | Minor | Major | Nil | Major | Minor-Moderate | Minor | Nil | Nil | Nil |
| 10. Possible level of costs required to meet effluent/emissions discharge standards | V.Low | Minor? | Nil | Major | Moderate-Moderate | Moderate? | Nil | Nil | Nil |</p>
<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>CATEGORY I</th>
<th>GRID EXTENSION</th>
<th>ENERGY ALTERNATIVES</th>
<th>CATEGORY III</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DIESEL</td>
<td>SMALL HYDRO</td>
<td>COAL</td>
<td>GEOThERMAL</td>
</tr>
<tr>
<td>11. Potential for negative wildlife habitat impacts</td>
<td>Low</td>
<td>Low-Moderate</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>12. Potential for negative fisheries impact</td>
<td>Nil</td>
<td>Moderate-Low</td>
<td>Moderate-High</td>
<td>Moderate-High</td>
</tr>
<tr>
<td>13. Possible overall level of costs associated with environmental mitigation</td>
<td>Nil</td>
<td>Low-Moderate</td>
<td>Moderate-High</td>
<td>Moderate-High</td>
</tr>
<tr>
<td>Social Energy Policy Variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14. Nature and type of energy source: Domestic (D), Canadian (C), Imported (I) / Renewable (R), Non-renewable (NR)</td>
<td>C/DI/NR</td>
<td>D/R</td>
<td>D/NR</td>
<td>D/R</td>
</tr>
<tr>
<td>15. Energy Conversion efficiency</td>
<td>30-40%</td>
<td>&gt;90%</td>
<td>30-50%</td>
<td>10-20%</td>
</tr>
<tr>
<td>16. System's potential for improved efficiency through conservation or improved technology</td>
<td>Good</td>
<td>Poor</td>
<td>Poor</td>
<td>Excellent</td>
</tr>
<tr>
<td>Government Administrative Variables</td>
<td>V.Low</td>
<td>Low-Moderate</td>
<td>High</td>
<td>Moderate-High</td>
</tr>
<tr>
<td>17. Probable level of government administrative/regulatory costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18. Possibility for public cost sharing in energy resource or project development</td>
<td>Nil</td>
<td>Nil-Moderate</td>
<td>Minor-High</td>
<td>Minor</td>
</tr>
<tr>
<td>19. Overall probable level of internalized social costs</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
<td>Moderate</td>
</tr>
</tbody>
</table>
quantitative parameters for socio-economic, environmental and political variables that are likely to be important as external constraints on the firm's efforts to maximize its objective function.

Selecting a preferred alternative may be accomplished either formally or informally (McAllister, 1980). Informal methods rely on judgemental evaluation and informed, subjective comparison of dissimilar values to arrive at a preferred choice or choices. Formal methods depend to varying degrees on the assignment of weighted values to criteria, in order to facilitate their comparison using mathematical procedures. MacCrimmon (1968) describes various formal decision making techniques with differing information requirements which can be applied to multiple-attribute problems. These include dominance, satisficing, maximin, lexicography, additive weighting, utility theory, non-metric scaling and others.

Dominance and satisficing are the procedures that will be used here to narrow the range of energy alternatives which can be advanced to the prefeasibility stage. These techniques are especially suited to dealing with multi-objective, multi-criteria problems in their full dimensionality. Dimensionality refers to the treatment of each criterion (dimension) separately and independently. This requires that each criterion must stand on its own. More rigorous decision making procedures that combine criteria to reduce the problem environment to one or a very few dimensions require more precise numerical specification of criteria values than can
normally be generated at the reconnaissance level of analysis.

The dominance procedure utilizes the concept of relative preference of one alternative over another. Thus alternative A is said to dominate alternative B if all A's criteria values are higher. If several alternatives have equivalent values for one or more criteria and higher values for specific criteria, but no one alternative is clearly dominant, then these may be referred to as admissible. If an alternative is equal to or worse than other alternatives for all criteria then it is said to be dominated and can clearly be excluded from the analysis.

In instances where it is not possible to precisely specify the values for criteria, this uncertainty can be reflected by specifying a range of values which represent reasonable upper and lower bounds of some probability distribution. If the range of values for alternatives then overlap, no one alternative may be clearly dominant. Rather, varying degrees of weak to strong dominance will be apparent.

Satisficing employs the procedure of applying minimum values for criteria to determine acceptable alternatives. If an alternative fails to satisfy a minimal value then it is excluded. Where an alternative narrowly fails to satisfy a minimal constraint, but is clearly acceptable for the majority, then the validity of the information which would cause the alternative to be rejected should be reviewed. Dominance and satisficing will be combined in the present analysis to narrow and clarify the preference for energy alternatives.

As an initial step in choosing among alternatives, the
mine planner may wish to specify certain minimal guidelines or pre-conditions. These can vary from one project to another, but for the present analysis for RED-CHRIS, the following conditions will apply:

(a) the power generation alternative must be commercially available at the present time.

(b) the power generation alternative must be able to come on stream in 5 years, a reasonable amount of time to bring a remote medium-sized deposit into production. For this study it will be assumed that a production decision has been reached for RED-CHRIS and that the deposit is scheduled to commence operation in 5 years.

(c) the power generation facility must be capable of being the mine's sole power source, i.e., it will ideally have a capacity factor approaching 100%, excepting shutdowns for periodic maintenance or efficiency improvements.

The alternatives can now be examined in light of these initial minimal conditions. If an alternative fails to satisfy one or more of these conditions then it is deleted from further consideration at this time. If the development of the deposit is deferred, than an alternative failing either (a) or (c) could be reconsidered.

Applying the requirement of commercial availability would appear to rule out both solar and wind at this time. While small-scale units and systems are presently available, large
units and arrays capable of meeting RED-CHRIS's power requirements are still largely in the experimental stage. All other alternatives meet this initial requirement.

The application of condition (b), a 5 year time frame for development, would rule out geothermal and seriously question the viability of either high voltage grid extension or natural gas pipeline construction. Concerning geothermal, recall that there is presently no proven geothermal energy field within economic transmission distance of the potential minesite and, therefore, construction lead time for geothermal power generation must allow for reservoir exploration and pilot testing of prospective geothermal fields.

Given the situation where both a high voltage grid extension or natural gas pipeline alternative could be completed in less than 5 years, or the situation where mine development was delayed beyond 5 years, then it would appear to be premature to delete these two alternatives from consideration at this time.

Application of the final initial condition, a system capacity factor of close to 100% does not permit further narrowing of the remaining field of 6 candidates because of uncertainty in the expected range of values. However based on this condition, alternatives can now be categorized into degrees of satisfying the overall set of conditions. Thus diesel, high voltage grid extension and a natural gas pipeline emerge as strongly satisfying initial conditions, given a marginal relaxation of the project start-up time. Small-hydro,
coal and biomass apparently emerge as relatively less capable of satisfying these conditions. Of these latter three, small-hydro could become a stronger candidate by improving its expected capacity utilization factor, for example by under-utilizing a hydrologic system with an assured surplus of water. This improvement might, however, be offset by potentially greater installation costs.

To summarize thus far, the application of three initial project conditions have allowed the mine planner to reduce his set of energy supply options from nine to six. Solar, wind, and geothermal have been deleted at this time.

In the next step, remaining alternatives are further examined by using dominance procedures applied to economic criteria. The most important economic criterion for comparing alternatives is a project's net present value. Net present values are calculated from gross investment costs and discounted anticipated average annual energy costs. Values for gross investment cost and average annual energy cost (mills/kWh) are summarized in Table XII. Net present values for diesel, small hydro, biomass, and coal alternatives are presented in Table XIV. Summaries of assumptions, capital and annual cost parameters used to determine the values in Table XIV are contained in Appendix 3. Net present values could not be determined for high voltage grid extension or natural gas pipeline options because their expected costs are unknown without detailed engineering assessment of route options or further knowledge of possible joint cost-sharing opportunities.
with other end users. Communications with Combustion Engineering officials in Ottawa confirmed that the economics of these two options are likely to be unfavourable relative to diesel, small hydro, biomass, and coal. Therefore grid extension and natural gas are deleted at this point.

Comparison of the values presented in Table XIV shows that small hydro clearly dominates the other three alternatives in both production scenarios and discount rate categories. Low annual costs are a major determinant in small hydro's economic favourability.

Coal is the second most dominant alternative, however its weak dominance must be qualified. Recall that the range of net present values for coal reflect uncertainty over capital and engineering costs, and that no allowance has been made for real price variations for coal feedstock. If coal prices were to increase in real terms, then it is conceivable that biomass would become more desirable than coal. Conversely, if coal prices were to experience real price decreases over the life of the RED CHRIS mine than coal would become competitive with small hydro given a 12% discount rate.

Biomass dominates diesel in nearly all categories except the 20-year low price 12% discount rate scenario. The reason for this reflects the greater sensitivity of diesel generation to annual fuel costs whereas petroleum derived fuels form a smaller component of annual biomass costs. Logging costs and environmental protection costs of biomass are presently very imprecise and may be a major cost factor on more detailed
Table XIV.

Summary of Net Present Value Estimates For RED CHRIS Power Generation

Alternatives ($Millions)

<table>
<thead>
<tr>
<th>PRODUCTION</th>
<th>DIESEL</th>
<th>SMALL HYDRO</th>
<th>BIOMASS</th>
<th>COAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCENARIO 1 : 8 YRS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Fuel Price Est.</td>
<td>$111.46</td>
<td></td>
<td>102.61</td>
<td></td>
</tr>
<tr>
<td>8%</td>
<td></td>
<td>63.30</td>
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<tr>
<td>High Fuel Price Est.</td>
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<td>120.80</td>
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<tr>
<td>Low Fuel Price Est.</td>
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<td></td>
<td>77.88</td>
<td></td>
</tr>
<tr>
<td>12%</td>
<td></td>
<td>53.77</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High Fuel Price Est.</td>
<td>$107.31</td>
<td></td>
<td>90.99</td>
<td></td>
</tr>
<tr>
<td>SCENARIO 2 : 20 YRS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Fuel Price Est.</td>
<td>$73.59</td>
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<td>67.98</td>
<td></td>
</tr>
<tr>
<td>8%</td>
<td></td>
<td>30.94</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High Fuel Price Est.</td>
<td>$115.13</td>
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<td></td>
</tr>
<tr>
<td>Low Fuel Price Est.</td>
<td>$48.07</td>
<td></td>
<td>52.86</td>
<td></td>
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<tr>
<td>12%</td>
<td></td>
<td>28.78</td>
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</tr>
<tr>
<td>High Fuel Price Est.</td>
<td>$71.52</td>
<td></td>
<td>57.01</td>
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</tr>
</tbody>
</table>
examination. This would tend to deteriorate biomass's apparent competitive advantage over diesel.

Finally, diesel is dominated by all other alternatives, a fact which reflects the large influence that diesel fuel prices have on this alternative's economics (fuel costs contribute on the order of 75-85% of net present value).

To summarize, the profile of candidates which has emerged from a comparison of net present value calculations is as follows. Small hydro strongly dominates all other alternatives. Coal exhibits weak to moderate dominance, while biomass is weakly to strongly dominated, and diesel is apparently dominated by all others. It is emphasized, however, that these net present values are preliminary in nature and would require more detailed investigation to establish definitive relationships. High voltage grid extension and natural gas are deleted from further consideration because available data are insufficient to allow meaningful cost comparisons.

The risk reduction criteria, technical reliability and technical improvement flexibility were examined for the four remaining alternatives but no major differences are apparent which would justify reducing the number of alternatives still further.

The final step in the mine planner's task of narrowing down feasible energy supply alternatives concerns the examination of social and governmental objective function variables, listed in Table XIII, as potential constraints on
the desirability of any one remaining alternative.

A number of socio-economic variables reflect costs that the firm might be required to internalize. The most important would appear to be associated with the potential for negative impacts on existing subsistence economies, and the potential for negative impacts on local native land claim options. Diesel is the preferred choice with very low impacts anticipated and hence few social costs to internalize. The greatest impacts and necessary mitigative costs would result from employing biomass and coal. However, the potential for biomass harvesting to create new wildlife habitat, thus improving local subsistence hunting, would be a beneficial externality which is not reflected in costs borne by the firm. The socio-economic costs attributable to small hydro can be minimized by careful site selection, compared to more rigid siting constraints for coal and biomass.

The important environmental costs constraining the firm's choice are potentially of the following two kinds: Costs required to meet effluent or emission standards, and mitigative costs related to various forms of biophysical alterations (land, water, wildlife). In both categories, diesel is once again clearly the dominant choice. Coal would clearly entail the greatest environmental costs, reflecting the process of mining coal, disposal of spent combustion residue typically with enhanced concentrations of toxic elements, venting of gaseous nitrogen and sulphur compounds, and the likely location of a coal-fired plant at the headwaters of major salmon fishery
streams (Skeena, Stikine, and Nass) adjacent to two provincial wilderness parks, Spatsizi and Tatlatutu. Although it appears that coal would be mined by Gulf Canada Resources, a company with no relationship to RED CHRIS owners, environmental costs borne by Gulf in mining coal would be passed on to the power-generation project in terms of coal price. The environmental costs resulting from employing small-hydro or biomass-fired generation can be minimized relative to coal because of greater design flexibility, however they still substantially exceed the costs resulting from diesel.

Social energy policy variables are important to the mine planner insofar as an energy supply alternative advocated as desirable by social energy policy may have some of its costs minimized through various forms of public development incentives. In recent years public energy policy has tended to favour abundant domestic energy resources capable of efficient conversion to usable energy forms. The order of preference for the four alternatives considering these policy constraints shows small-hydro dominant, followed by biomass, coal and diesel.

Finally, the mine planner's choice will be constrained by an overall level of anticipated internalized social costs arising from government regulatory activities. The more regulated the project, the greater will be costs borne by the developer. Of the four alternatives, diesel is anticipated to be the least regulated and hence least costly in this category. Since both biomass and coal involve extractive and transport
activities and relatively greater labour forces not necessary for either diesel or small-hydro, both coal and biomass will likely be subject to more intensive regulation and the social costs borne by the mine developer will be accordingly higher. Small hydro is anticipated to be intermediate between diesel and the coal or biomass. Internalized social costs attributable to small hydro could substantially increase if poor siting resulted in conflicts with productive fisheries.

To summarize the socio-economic, environmental, policy, and governmental analysis then, it is clear that diesel is the dominant choice in all categories except social energy policy. However, failure to "conform" to the ideals of social energy policy does not readily translate into direct costs borne by the firm employing diesel powered generation. Hence the internalized social costs are anticipated to be a minimum for this alternative. Small hydro is second to diesel in all categories except social energy policy where it clearly dominates all others. Biomass is generally an admissible alternative, it exhibits weak dominance in environmental and social energy policy categories, while being clearly dominated in socio-economic and governmental categories. Coal is dominated in all categories except social energy policy where it dominates diesel. Thus the social costs likely to be internalized by the firm are anticipated to be greatest for coal out of these four alternatives.

If these results are now merged with the previous results after examining the alternatives with the firms objective
function variables, the following conclusions can be made. Small hydro is a highly favourable energy supply alternative exhibiting the lowest net present value of the four finalists, design flexibility and generally low anticipated internalized social costs. Diesel is a favourable alternative from nearly every perspective except overall economics and energy policy. Unless it can be demonstrated that diesel fuel will experience real price decreases over the life of the mine, thereby improving diesel generation economics, there is, however, little justification for promoting diesel as a sole power source for consideration at the prefeasibility stage of analysis. Biomass and coal are generally comparable. Net present value calculations demonstrate that coal is more favourable than biomass if non-petroleum fuel feedstocks for both alternatives experience no real price fluctuations. Conversely, the higher anticipated social, environmental, and regulatory costs related to coal-fired power generation would tend to erode its comparative economic advantage and tend to favour biomass as a better overall alternative. Biomass and coal should be modelled in greater detail at the prefeasibility stage of analysis so that an unequivocal comparison with small hydro may be achieved. High voltage grid extension and natural gas pipeline options require further cost study and deferred mine development to be reconsidered along with the previous four. Geothermal, solar, and wind are not likely to be viable alternatives for many years.
6.4. PERIPHERAL STRATEGIC DATA

Peripheral strategic data base information concerns regional development and other trends which are independent of the focused problem, but which can exact important influence on overall mine feasibility and selection of energy supply alternatives for RED-CHRIS. Four peripheral areas are briefly introduced below. Each area could provide the focus of a much larger study.

6.4.1. Peripheral Data Base I - Status of Mineral Deposit Development Adjacent to RED-CHRIS

Mineral deposits where exploration and development are sufficiently advanced and therefore potentially influential in RED-CHRIS's development are: Schaft Creek, Mt. Klappan, and possibly Kutcho Creek.

Schaft Creek copper and molybdenum deposit is located 75 kilometres southwest of RED-CHRIS. Development of the deposit by TECK CORPORATION, its present owners, is essentially at the feasibility stage. Given that the mine's townsite location will be adjacent to Highway 37, and power supplied from either More Creek, Klappan Coal, or grid/pipeline extensions from the south, then the economics of energy supply at RED-CHRIS would most certainly be improved.

Mt. Klappan coal deposit is situated 50 kilometres southeast of RED-CHRIS adjacent to the abandoned B.C. Railway grade. The planned development of Mt. Klappan by Gulf Canada Resources perhaps within 5 years, might substantially improve energy supply economics for RED-CHRIS, given that Mt. Klappan
relies on either coal-fired or grid extension power supply. Access and community infrastructure benefits are less likely to influence RED-CHRIS because Mt. Klappan commodity inflow and outflow, access/egress will occur from the southwest.

Kutcho Creek copper, zinc, and gold deposits situated 100 kilometres northeast of RED-CHRIS is a major potential underground mine at the feasibility stage. The deposit's development and required infrastructure are unlikely to influence RED-CHRIS unless power supply is secured from the south via Highway 37 or the B.C. Railway corridor, in which case shared transmission costs may be realized.

6.4.2. Peripheral Data Base II - Mineral Commodity, Price, Demand/Supply Trends

The metal price for copper and gold directly determine the status of RED-CHRIS development viability. Metal prices and anticipated metal price trends can accelerate or defer mine development. Under a scenario of accelerated mineral development (high price scenarios), energy supply alternatives with short lead times, few uncertainties, and few regulatory constraints will be favoured. Conversely, under a deferred scenario (low price forecast), a greater range of energy alternatives can be considered. Furthermore, new technological or economic factors may emerge that would improve the favourability of previously less favourable options. Copper prices at present reflect the latter scenario.

A recent survey of mineral analyst forecasts by
economists of the Mineral Policy and Evaluation Branch of the Ministry of Energy, Mines and Petroleum Resources (1983) concluded that the long run outlook for copper prices was for positive real price increases, punctuated by short-term downward cycles. The major area of uncertainty is therefore, the rate of real price increases.

6.4.3. Peripheral Data Base III - Government Regional Mineral Development Policy

Government policy regarding development of the northwest's mineral resources is still in the formative stages.

The Interministry Working Group on Northwest British Columbia's (1982-1984) recently completed series of preliminary studies did not present specific regional resource development policies. Nevertheless, governmental concern for orderly resource development in consideration of all social and environmental issues emerged. Government appears ready to assist in areas of community, transportation, and port facility construction (as for Northeast Coal), while simultaneously promoting private investment whenever possible. No new government policies have been suggested to alleviate the energy supply problems facing nearly every mineral deposit in the northwest.

6.4.4. Peripheral Data Base IV - Changing Land Use Patterns

Changing land use patterns or management adjacent to RED-CHRIS could potentially alter the favourability of several indigenous energy supply alternatives such as biomass-fired
generation, and small hydropower. For example, commercial timber harvesting near RED-CHRIS could alter the volume and quality of biomass available for combustion, and increase the cost of procurement. Similarly, fisheries enhancement or private micro-hydro development could reduce the number of potentially available sites, and increase costs at prime sites.

Native land claims could potentially alter the favourability of grid extension or pipeline alternatives which cross expansive tracts of land utilized by native peoples for subsistence hunting and gathering.

The sensitivity (and hence desirability) of energy supply alternatives to minor shifts in costs, and the ability of certain land uses to preclude consideration of specific energy alternatives underline the need for mineral deposit owners to become involved in regional land use planning deliberations. Conversely, the potential for social and environmental impacts arising from development of energy supply alternatives underlines the need for local interests to be familiar and involved with resource development planning.

6.5. FURTHER RESEARCH NEEDS

An axiomatic feature of a reconnaissance level evaluation is the need for further research. Further research should strive towards a more precise focusing of the problem area in order to reduce uncertainty, while maintaining an appropriate balance of simplicity and complexity. The types of additional information requirements identified may be costlier and more
time-consuming to generate. This underlines the need for continuing assessment of priorities to ensure cost-effective allocation of analytical resources.

The foregoing analysis has demonstrated the need for further research in two principal areas; refinement of existing data, and ongoing or iterative analysis.

Further research in the core information environment could be effectively employed in the following areas:

(a) Interest groups and objectives - There is additional scope to further define interest group interests and to develop a clearer appreciation for the types of impacts they are likely to experience from the activities of mine development. Moreover, key interest group attitudes towards risk related to energy project development are presently unclear.

(b) Mineral deposit energy demand - Further refinement of the energy demand estimations derived for RED-CHRIS are contingent on a more rigorous development of three interrelated sub-models: an up-dated three dimensional geological model with latest known distributions of mineral grades and mining characteristics (i.e., rock hardness, fracturing) specified, from which a conceptual mining plan may be developed; a mineral processing model based on metallurgical characteristics of RED-CHRIS ore; and a conceptual model of infrastructure (housing, transportation) siting, and design.

(c) Regional influences - Two areas of further research are indicated: a more precise characterization of the development problems and opportunities facing potential mining,
hydroelectric or forestry operations adjacent to RED-CHRIS; and
a better understanding of the nature of, and requirements for,
native subsistence economies. The former is important insofar
as opportunities to reduce RED-CHRIS's development costs may be
suggested. In the latter case, strategies can be formulated to
minimize potential social impacts and minimize potentially
unnecessary internalized social costs.

The objective of further research in the basic evaluation
environment is to achieve a more confident selection of
feasible energy supply alternatives. Presently, considerable
uncertainty exists for various alternatives in determining
their values for specific criteria. This is reflected by wide
ranges in expected costs and benefits and qualitative
assessment of key socio-economic variables. One approach might
be to direct research efforts to improving information for a
narrowed set of alternatives during a second iteration of the
analysis. Sensitivity analysis using different discount rates,
project financing scenarios, and fuel price trend modelling are
activities that could be pursued during the second iteration.

An area of deficient knowledge that would warrant some
investigation concerns the relationship of regulatory
requirements to the economics of small energy projects for
northern mining. Clearly, the nature of, and differences
between regulatory processes for the various preferred
alternatives is an important area of cost uncertainty from both
public and private perspectives.

Finally, it is apparent that components outlined in the
peripheral environment can exert a profound affect on the viability of energy supply alternatives and indeed on the viability of RED-CHRIS as a mine. Metal prices, native and often provincial land-use deliberations, and government regional development policies, all deserve close monitoring to assess whether relative changes in their status enhance or diminish the viability of RED-CHRIS as a potential mine, and alter its potential energy supply options.

6.6. CONCLUSIONS

The purpose of this chapter was to perform a reconnaissance level evaluation of potential energy supply options available for development of the RED-CHRIS copper-gold deposit. This was achieved by applying the methodology outlined in Chapter Four. The examination of energy alternatives and their final selection was performed from the perspective of a mine planner subject to constraints imposed by public and governmental interests. The main conclusions which emerged from the analysis are outlined below:

(1) Interest groups concerned with the planning, development, outcome or regulation of an energy supply project are divisible into three categories each with its corresponding objective function. Objective Group A represents mineral deposit owners who have as their objective, the desire to maximize profit. Objective Group B includes diverse interests directly or indirectly affected by the proposed energy project who have as their general objective the
desire to maximize economic and social well-being, and environmental integrity. Objective Group C represents two components of societal interest relevant to the problem area: public energy policy, and government administrative interests. The overall objective of these categories is to maximize economic, political and social welfare pertaining to specific policy and administrative areas.

(2) RED-CHRIS represents a large-tonnage low grade copper gold deposit extractable by open-pit mining methods. RED-CHRIS has many similar characteristics to other porphyry-style deposits in the circum-Pacific region and hence their energy use data can be used to derive gross energy requirements for RED-CHRIS. Gross energy requirements are estimated to range from 7.5 to 23.5 megawatts installed capacity for an 8 to 20 year production schedule. These estimates require further refinement based on conceptual models of the deposit's geology, ore processing, and infrastructure.

(3) Energy supply options for RED-CHRIS may be influenced by other regional mining and non-mining industrial development and native land claim negotiations. For example, development of Gulf Canada Resource's Mt. Klappan anthracite deposit may provide coal-fired electric generating capacity within economic transmission distance of RED-CHRIS.

(4) Energy supply options considered for RED-CHRIS can be categorized as: (1) commercially proven and with historical
application to remote mining (e.g., diesel-electric, high voltage grid extension, small-hydro); (ii) commercially proven but without historical application to remote mining (e.g., coal-fired generation, biomass, natural gas, peat, geothermal); and (iii) commercially doubtful and without historic application to remote mining (e.g., solar and wind).

(5) Satisficing and Dominance procedures, methods of formal multi-attribute decision-making can be successfully applied from a mine planner's perspective to evaluate, select and rank a reduced group of alternatives for advancement to the prefeasibility stage of analysis. Simultaneously, areas of priority research can be identified for these alternatives. Similar success in the application of these decision-making techniques to analyses carried out from the other interest group perspectives would need to be investigated.

(6) Diesel, small-hydro, biomass and coal-fired electric generating options, in order, appear to be the most feasible energy supply alternatives for RED-CHRIS at this time.

(7) Cost-effective application of resources to further research should concentrate on refining existing data and analyses, and on monitoring peripheral influences, such as metal price trends, which are important from the standpoint of overall project viability.
CHAPTER SEVEN

CONCLUSIONS

The central objective of this study has been to develop and test a methodology capable of reconnaissance level evaluation of energy supply alternatives for future medium-scale mineral development in British Columbia's northwest. The principal conclusions which emerge from this study are as follows:

(1) Northwest British Columbia contains a diversity of natural resources which are generally underutilized, undeveloped or poorly documented. Public preferences pertaining to the use, allocation, and management of these resources range from those who desire a cautious, environmentally sound, slow pace of economic development in order to preserve a quality wilderness lifestyle and give time to resolution of aboriginal land claims, to those who view an enhanced pace of economic development primarily through diversified mining, forestry and energy activities as providing the cornerstone of future regional prosperity and stability. Resource management decisions made today must take into account uncertain knowledge about resource distribution and disparate public policy objectives.

(2) Mineral resources in the study area present the most immediate potential for large-scale, regional, industrial development. However, this development is presently constrained by weak metal prices, insufficient transportation
and community facilities and lack of low-cost electrical power. (3) Energy supply for mining remains an unresolved issue despite several recent government studies of the problem. Given the wide range of potential mining scales, timing and impact, and the existing regulatory parameters governing new energy projects as specified by the provincial Utilities Commission Act, it is concluded that the most effective reduction of uncertainty for this issue is achieved through the development of a strategic analytical framework. This analytical framework would specifically focus on assessing power options for individual medium-scale potential mines. (4) A strategic analytical framework which addresses the issues of this study can be derived from commonly advocated principles of normative decision-making, strategic analysis, and multi-attribute decision-making procedures, in conjunction with energy project evaluation approaches reflecting the objective functions of various interest groups. (5) The methodology permits the effective analysis of energy supply options for a deposit to be conducted in three stages: (i) a Core Information Environment focuses the problem environment and establishes a perspective for the subsequent analysis; (ii) a Basic Evaluation Environment identifies, evaluates and ranks feasible alternatives for problem resolution; and (iii) a Peripheral Evaluation Environment identifies and examines the influence of areas of uncertainty which may alter the outcome of the analysis but are external to the decision-maker's control.
(6) It is concluded from the mine planners point of view, that for RED-CHRIS copper-gold deposit, the most feasible energy supply options at this time are: small hydroelectric power generation, biomass-fired power generation, and coal-fired power generation. Diesel-electric generation may be more or less favourable than coal or biomass depending on price assumptions, but is clearly less favourable than small hydroelectric.

(7) The case-study analysis was carried out from the mine planners perspective and is therefore influenced by that interest group's values. It is anticipated that if the analysis were to be conducted from a different interest group's perspective, the results may well differ. This dilemma, and reality, of public policy analysis illustrates why the methodology is structured to be adaptable, yet requires an explicit enunciation and accounting of competing interest group objective and priority evaluation criteria. It is therefore recommended that the degree of value sensitivity of the methodology be tested by applying it from more than one perspective to the same mineral deposit.

(8) It is concluded that the methodology is sufficiently comprehensive and robust to be adapted to other mineral deposits in the region. Such an application will be able to benefit from the RED-CHRIS case study because of similarities in interest group objectives, technical and economic aspects of energy supply alternative basic information, and analogous peripheral evaluation information pertaining to metal price
trends and government policy for example. The iterative nature of information processing, promoted by implementing the methodology, can be used to improve the efficiency of subsequent applications to other deposits.

(9) The utility of the methodology may be diminished where clusters of mineral deposits occur, suggesting different levels of resource information and development timing. This limitation may be partially overcome by detailed conceptual modelling and construction of a range of anticipated development scenarios.

Finally, it is concluded that it has been possible to demonstrate in this study that a focused and rigorously applied public policy analysis of energy supply issues facing mining development in northwest British Columbia, can produce positive reductions in uncertainty through the development of a strategic energy project evaluation methodology.
BIBLIOGRAPHY


146. Residents for a Free Flowing Stikine, ca., 1980. Save the Stikine - Stop the Dams! Telegraph Creek, B.C., 8 p.


We, the undersigned members of the Tahltan tribe, speaking for ourselves, and our entire tribe, hereby make known to all whom it may concern, that we have heard of the Indian Rights movement among the Indian tribes of the Coast, and of the southern interior of B.C. Also, we have read the Declaration made by the chiefs of the southern interior tribes at Spences Bridge on the 16th July last, and we hereby declare our . . . Intention to join with them in the fight for our mutual rights, and that we will assist in the furtherance of this object in every way we can, until such time as all these matters of moment to us are finally settled. We further declare as follows:

Firstly — We claim the sovereign right of all the country of ours which we have held intact from the encroachments of other tribes, from time immemorial, at the cost of our own blood. We have done this because our lives depended on our country. To lose it meant we would lose our means of living, and therefore our lives. We are still, as heretofore, dependent for our living on our country, and we do not intend to give away the title to any part of same without adequate compensation. We deny the B.C. government has any title or right of ownership in our country. We have never treated with them, nor given them any such title. (We have only very lately learned the B.C. government makes this claim, and that it has for long considered as its property all the territories of the Indian tribes in B.C.).
Secondly — We desire that a part of our country, consisting of one or more large areas (to be selected by us), be retained by us for our own use, said lands, and all thereon to be acknowledged by the government as our absolute property. The rest of our tribal land we are willing to relinquish to the B.C. government for adequate compensation.

Thirdly — We wish it known that a small portion of our lands at the mouth of the Tahltan River, was set apart a few years ago by Mr. Vowell as an Indian reservation. These few acres are the only reservation made for our tribe. We may state we never applied for the reservation of this piece of land, and we had no knowledge why the government set it apart for us, nor do we know exactly yet.

Fourthly — We desire that all questions regarding our lands, hunting, fishing, etc., and every matter concerning our welfare, be settled by treaty between us and the Dominion and B.C. governments.

Fifthly — We are of the opinion it will be better for ourselves, also better for the governments and all concerned, if these treaties are made with us at a very early date, so all friction, and misunderstanding between us and the whites may be avoided, for we hear lately much talk of white settlement in this region, and the building of railways, etc., in the near future.

Signed at Telegraph Creek, B.C., this eighteenth day of October, nineteen hundred and ten, by

NANOK
Chief of the Tahltans.
NASTULTA
alias Little Jackson.
GEORGE ASSADZA, KENETL
alias Big Jackson, and eighty other members of the tribe.
THERE IS NO PAGE 258.

Appendix 2 is an oversize map, filed in map cabinet in Special Collections Division, UBZ Library.
APPENDIX 3

Net Present Value Calculations for Diesel, Small Hydro, Biomass, and Coal Power Generation Alternatives

The following pages present general assumptions and general cost estimates for four power generation alternatives reviewed in greater detail in Chapter 6. The availability and accuracy of the following information is highly variable as the reader will notice. For example, data for diesel and small hydro are generally more available for remote installations, hence the present value calculations are correspondingly more accurate.

To facilitate as common a comparison as possible, all cost data researched were adjusted to 1984 dollars and then inflated at 5% per annum to installation dates prior to discounting. Annual costs were discounted using 1990 as year 1 and continuing for 8 and 20 years as appropriate. Real price increases for petroleum fuels are incorporated. It is assumed that capital costs are paid for in the year they are incurred, i.e., not amortized over the mine life.

Improvements in these assumptions may be possible at a more detailed level of study, however their consistent application in the following pages will at the least permit a reasonable comparison of net present values at the reconnaissance level of analysis.
Diesel-Electric Plant Costs

GENERAL ASSUMPTIONS:

1) In Service Date: 1990

2) Installation Schedule:\n   Engineering, site preparation, buildings - 40% costs.
   2 years prior to in service date.
   Equipment purchasing, delivery and installation - 60% costs.
   1 year prior to in service date.

3) Standby Installation Capacity: 25% of peak demand capacity.


     see Table for low/high price scenario.
   Labour, parts and materials - @ 15% of 1984 fuel costs.
   Lube, oil and petroleum products - @ 1.9% of annual fuel cost.

6) No Salvage Value

SCENARIO i - RED-CHRIS PRODUCTION - 8 YEARS

1) Low energy consumption estimate.
2) Mobile unit installation.
3) Peak Demand Capacity - 18.8 mW.
4) Total Installed Capacity - 23.5 mW.
5) Annual energy produced @ 85% Load Factor - 139.67 million kWh.
SCENARIO 2 - RED-CHRIS PRODUCTION - 20 YEARS

1) Low energy consumption estimate.
2) Stationary unit installation.
3) Peak Demand Capacity - 7.5 mW.
4) Total Installed Capacity - 9.0 mW.
5) Annual Energy Produced @ 85% Load Factor - 55.86 million kW.

SUMMARY OF PRESENT VALUE CALCULATIONS FOR DIESEL-ELECTRIC PLANT

DISCOUNT RATE

<table>
<thead>
<tr>
<th>SCENARIO 1 (8 YEARS)</th>
<th>8%</th>
<th>12%</th>
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</thead>
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<tr>
<td><strong>LOW FUEL PRICE</strong></td>
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</tr>
<tr>
<td>$K = 19.27$</td>
<td>$16.32$</td>
<td></td>
</tr>
<tr>
<td>$O&amp;M = 92.19$</td>
<td>$66.33$</td>
<td></td>
</tr>
<tr>
<td>$T = 111.46 \text{ million}$</td>
<td>$82.65 \text{ million}$</td>
<td></td>
</tr>
<tr>
<td><strong>HIGH FUEL PRICE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$K = 19.27$</td>
<td>$16.32$</td>
<td></td>
</tr>
<tr>
<td>$O&amp;M = 127.31$</td>
<td>$90.99$</td>
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<tr>
<td>$T = 146.58 \text{ million}$</td>
<td>$107.31 \text{ million}$</td>
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</table>

<table>
<thead>
<tr>
<th>SCENARIO 2 (20 YEARS)</th>
<th>8%</th>
<th>12%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LOW FUEL PRICE</strong></td>
<td></td>
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<tr>
<td>$K = 8.31$</td>
<td>$7.04$</td>
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<td>$O&amp;M = 65.28$</td>
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<td>$T = 73.59 \text{ million}$</td>
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<tr>
<td><strong>HIGH FUEL PRICE</strong></td>
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<tr>
<td>$O&amp;M = 106.82$</td>
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<td>YEAR</td>
<td>LOW PRICE SCENARIO (1% P.A.)</td>
<td>HIGH PRICE SCENARIO (5% P.A.)</td>
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<tr>
<td>------</td>
<td>-----------------------------</td>
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<tr>
<td>1984</td>
<td>44.4 c/litre</td>
<td>44.4 c/litre</td>
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<tr>
<td>1985</td>
<td>44.84</td>
<td>46.62</td>
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<td>1986</td>
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<td>1987</td>
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<td>1988</td>
<td>46.20</td>
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<td>1989</td>
<td>46.66</td>
<td>56.67</td>
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<tr>
<td>1990</td>
<td>47.13</td>
<td>59.50</td>
</tr>
<tr>
<td>1991</td>
<td>47.60</td>
<td>62.48</td>
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<tr>
<td>1992</td>
<td>48.07</td>
<td>65.60</td>
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<td>1993</td>
<td>48.56</td>
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<td>1994</td>
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<td>1995</td>
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<td>1996</td>
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<td>1997</td>
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<td>1999</td>
<td>51.54</td>
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<td>2003</td>
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<td>112.20</td>
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<td>54.17</td>
<td>117.81</td>
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<td>2005</td>
<td>54.71</td>
<td>123.70</td>
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<tr>
<td>2006</td>
<td>55.26</td>
<td>129.88</td>
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<td>2007</td>
<td>55.81</td>
<td>136.38</td>
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<td>2008</td>
<td>56.37</td>
<td>143.19</td>
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<tr>
<td>2009</td>
<td>56.93</td>
<td>150.35</td>
</tr>
</tbody>
</table>

2,3Ibid, B.C. Hydro estimate inflated 8% to 1983, 6% to 1984, includes site preparation, units, auxiliaries, buildings, and fuel storage.


5PetroCanada verbal quote in September 1984 for diesel fuel delivered to Cassiar (120 km. north of RED-CHRIS).
SMALL HYDRO PLANT COSTS

SCENARIO 1 - RED-CHRIS PRODUCTION - 8 YEARS

GENERAL ASSUMPTIONS:

1) In service date: 1990

2) Total Installed Capacity: 23.5 MW.

3) Peak Demand Capacity: 18.8 MW.

4) Annual Energy Produced at 85% Load Factor - 139.67 million kWh.

5) Site: Burrage Creek. See Appendix 2 for location.

6) Site characteristics (modified from Table VIII to conform to run of river to reduce costs by not having to construct dam proposed in Table VIII).
   - Drainage area = 580 km².
   - Design flow = 24.7 m³/second.
   - Fraction firm = 0.5.
   - Gross Head = 136 metres.
   - Canal length = 5000 metres (lined for ice cover);
     1:1 side-cut slope; 5:1 cross-cut slope.
   - Penstock length = 1606 metres.
   - Access construction = 7 kilometres total.
   - Transmission Line kV/distance = 230 kV/55 kilometres.


SITE DERIVED PARAMETERS FOR COST DETERMINATIONS

1) Canal Excavated Volume = 200 m³/metre.

2) Canal Concrete Volume = 2.7 m³/metre.

3) Weir Dimensions = 3 metres x 200 metres.

4) Penstock Diameter = 2.88 metres.

5) Penstock Average Thickness = 0.0174 metres.

6) Penstock Weight = 1.988 million kilograms.

7) Turbine Type = Francis.

8) Specific Speed (ns) = about 110.

9) Turbine Rpm = about 1200.
10) Turbine Runner diameter = 2.02 metres.

11) Powerhouse Dimensions = 25.8 metres x 55.4 metres.

12) Site Cost Factor = 1.5.

### SUMMARY OF COSTS

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Canal Excavation</td>
<td>$3410</td>
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<tr>
<td>2) Canal Concrete</td>
<td>$3280</td>
</tr>
<tr>
<td>3) Weir</td>
<td>$210</td>
</tr>
<tr>
<td>4) Intake</td>
<td>$1520</td>
</tr>
<tr>
<td>5) Penstock (steel)</td>
<td>$13233</td>
</tr>
<tr>
<td>6) Powerhouse</td>
<td>$4150</td>
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<td><strong>SUBTOTAL</strong></td>
<td>$25,803</td>
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<tr>
<td>Site Factor Adjustment (X 1.5)</td>
<td>$38,710</td>
</tr>
<tr>
<td>7) Generating Equipment</td>
<td>$3630</td>
</tr>
<tr>
<td>8) Access</td>
<td>$970</td>
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<td><strong>SUBTOTAL</strong></td>
<td>$43,310</td>
</tr>
<tr>
<td>20% Engineering Cost</td>
<td>$8660</td>
</tr>
<tr>
<td>15% Contingency Allowance</td>
<td>$6490</td>
</tr>
<tr>
<td><strong>SUBTOTAL</strong></td>
<td>$52,000</td>
</tr>
<tr>
<td>9) Transmission Line</td>
<td>$5320</td>
</tr>
<tr>
<td>10) Switchyard</td>
<td>$908</td>
</tr>
<tr>
<td><strong>TOTAL CAPITAL</strong></td>
<td>$64,690,000</td>
</tr>
</tbody>
</table>

Annual Operating and Maintenance @ 1% $647,000

Water Rent payable to B.C. Government @ 0.314/kWh $438,564

**TOTAL ANNUAL** $1,085,564
SCENARIO 2 - RED-CHRIS PRODUCTION - 20 YEARS

GENERAL ASSUMPTIONS¹

1) In service date: 1990.

2) Total Installed Capacity: 9.1 mW.

3) Peak Demand Capacity: 7.5 mW.

4) Annual Energy Produced at 85% Load Factor: 55.86 million kWh.

5) Site: Little Iskut River. See Figure 2 for location.

6) Site Characteristics (modified from Table VIII to include a combination of canal and penstock to reduce costs).
   - Drainage area = 366 km².
   - Design flow = 21.2 m³/second.
   - Fraction firm = 0.5 (minimum).
   - Gross head = 60 metres.
   - Canal length = 6500 metres (lined for ice cover); 1:1 side-cut slope; 5:1 cross-cut slope.
   - Penstock length = 1002 metres.
   - Access Construction = 14 Kilometres total.
   - Transmission Line kV/distance = 138 kV/45 kilometres.

7) Construction Schedule: 1988 (20%), 1989 (80%).

SITE DERIVED PARAMETERS FOR COST DETERMINATIONS²

1) Canal Excavated Volume = 170 m³/metre.

2) Canal Concrete Volume = 2.55 m³/metre.

3) Weir Dimensions = 3 metres x 100 metres.

4) Penstock Diameter = 2.67 metres.

5) Penstock Average Thickness = 0.0086 metres.

6) Penstock Weight = 569,768 kilograms.

7) Turbine Type = Francis.

8) Specific Speed (ns) = about 160.

9) Turbine Rpm = about 300.

10) Turbine Runner diameter = approx. 1.7 metres.
11) Powerhouse Dimensions = 14.2 metres x 33 metres.
12) Site Cost Factor = 1.5.

**SUMMARY OF COSTS**

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Canal Excavation</td>
<td>$3731</td>
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<tr>
<td>2) Canal Concrete</td>
<td>3927</td>
</tr>
<tr>
<td>3) Weir</td>
<td>94.5</td>
</tr>
<tr>
<td>4) Intake</td>
<td>1307</td>
</tr>
<tr>
<td>5) Penstock (steel)</td>
<td>3654</td>
</tr>
<tr>
<td>6) Powerhouse</td>
<td>1361</td>
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<td><strong>SUBTOTAL</strong></td>
<td><strong>$14,074.5</strong></td>
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<tr>
<td><strong>SITE ADJUSTMENT FACTOR (X 1.5)</strong></td>
<td><strong>$21,111.7</strong></td>
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<tr>
<td>7) Generating Equipment</td>
<td>3025</td>
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<tr>
<td>8) Access</td>
<td>1525</td>
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<tr>
<td><strong>SUBTOTAL</strong></td>
<td><strong>$25,662</strong></td>
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<tr>
<td>20% Engineering Cost</td>
<td>5134</td>
</tr>
<tr>
<td>15% Contingency Allowance</td>
<td>3849</td>
</tr>
<tr>
<td>9) Transmission Line</td>
<td>4356</td>
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<tr>
<td>10) Switchyard</td>
<td>605</td>
</tr>
<tr>
<td><strong>TOTAL CAPITAL</strong></td>
<td><strong>$39,604,000</strong></td>
</tr>
</tbody>
</table>

Annual Operating and Maintenance @ 1% $396,000
Water rent payable to B.C. Government @ 0.314c/kWh 124,658

**TOTAL ANNUAL** $520,658
### SUMMARY OF PRESENT VALUE CALCULATIONS FOR SMALL HYDRO

#### DISCOUNT RATE

<table>
<thead>
<tr>
<th>SCENARIO 1</th>
<th>8%</th>
<th>12%</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 Year Production Schedule (Burrage Cr)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$ K = $57.61 million</td>
<td>$ K = $49.67 million</td>
<td></td>
</tr>
<tr>
<td>$ O&amp;M = $5.69 million</td>
<td>$ O&amp;M = $4.10 million</td>
<td></td>
</tr>
<tr>
<td>$ T = $63.3 million</td>
<td>$ T = $53.77 million</td>
<td></td>
</tr>
</tbody>
</table>

| SCENARIO 2 | | |
| 20 Year Production Schedule (Little Iskut) | | |
| $ K = $27.05 million | $ K = $26.31 million |
| $ O&M = $3.89 million | $ O&M = $2.47 million |
| $ T = $30.94 million | $ T = $28.78 million |

1 General parameters for site location were determined from detailed examination of surveys and mapping 1:50,000 scale topographic maps, measurements performed on stereographic analysis of B.C. vertical black and white air photographs, and Ministry of Environment hydrographic records.


BIOMASS-FIRED POWER GENERATION COSTS

GENERAL ASSUMPTIONS:

1) In service date: 1990.

2) Installation Schedule:
   Year 1 - Engineering, site preparation, buildings - 30%.
   Year 2 - Equipment purchasing, delivery, logging startup - 70%.

3) System type: Conventional wood-fired boiler utilizing
   steam/turbine.

4) Biomass fuel cost\textsuperscript{1}: $18.1 to $23.5/m\textsuperscript{3} @ 50% moisture content.

5) Auxiliary oil\textsuperscript{2}: 44.4c/l delivered to Cassiar (1984).
   See Diesel for price increase estimates.

SCENARIO 1 - RED-CHRIS PRODUCTION - 8 YEARS

1) Installed Capacity\textsuperscript{3}: 2 x 5,000 kW Boiler/steam turbine
   generator set.

2) Peak Demand Capacity: 8500 kW (7500 kW required).

3) Steam Conditions: Pressure at turbine throttle 4237 kPa.

4) Back Pressure at Condensor: 10 kPa.

5) Fuel Storage, Ash Disposal and Electrical System details unknown.

6) Operation and Maintenance\textsuperscript{4}: 3.0% of capital costs.
### SUMMARY OF COSTS\(^5\) ($1984 \times 1,000)

**Capital Costs:**

1. Site Development allow $ 500  
2. Civil Works 4730  
3. Mechanical Works 13310  
4. Electrical Works 4730  
5. Cooling Water System allow 500  
6. 1 year oil storage @ 3.0c/l 1.9

**SUBTOTAL** $23,960

7. Construction Engineering and Project Management @ 20% $ 4792  
8. Contingency @ 15% 3594

**TOTAL CAPITAL** $32,346,000

**Annual Costs:**

1. Auxiliary Oil (3,014,000 l)=1,338 $ 1338  
2. Operation and Maintenance @ 3%K=970 970  
3. Biomass Harvesting Cost @ $18.1 to $23.5/m\(^3\) $ 2317 to 3008

**TOTAL ANNUAL ($1984)** $4,625,500 to $5,316,500

---

**SCENARIO 2 - RED-CHRIS PRODUCTION - 20 YEARS**

1. Installed Capacity - 21.7 mW.

2. System design\(^6\) - Combined cycle system using pressurized Omnifuel Gasifier and Westinghouse 191 D Turbine

3. Gas quality assumed for turbine - Co 12.3 vol.%; H\(_2\) 8.4 vol.%; C\(_x\)H\(_y\) 2.0 vol.%; N\(_2\),H\(_2\)O,CO\(_2\) balance.

4. Average heating value of gas - 5.5 MJ/Nm\(^3\).

5. Temperature after cooling - 425°C.

6. Biomass feed requirements - 87 m\(^3\)/hr (2100 m\(^3\)/day).
7) Turbine booster air characteristics - Inlet pressure 620 kPag
    @ 4350 m³/hr.
    - Outlet pressure 1137 kPag.
    - Ratio 1.7:1
    - 670 kW.

8) Turbine characteristics
    - Fuel Input 74 MW.
    - Electrical Output 21.7 MW.
    - Efficiency 29.4%.
    - Exhaust Mass Flow 131 kg/sec.
    - Exhaust temperature 452°C.
    - Energy Available 37.5 MW @ 176°C.
    - Overall Efficiency 80.2%.

9) Overall System Performance - Biomass Consumption = 18,950 kg/hr dry.
    - Turbine Power = 21.0 MW.
    - Steam Production = 47,600 kg/hr.
    - Steam Turbine Electricity = 8.6 MW.
    - Electricity Consumption = 1.0 MW.

10) Site Factor - 1.5.

SUMMARY OF COSTS ($1984 X ,000)

Capital Costs:

1) Site Preparation $ 660
2) Wood Handling (Unloading
    Hogging, Storage, Feed) 6930
3) Civil Works 825
4) Gasifier 4961
5) Gas Cleanup 880
6) Turbine / Generator 9460
7) Waste Heat Recovery 2860
8) Steam Turbogenerator 4422

SUBTOTAL CAPITAL $30,998,000

Annual Costs:

1) Operation and Maintenance
    @ 5.0% of K $ 1830
2) Biomass Cost 642,600 m³/yr
    x $18.1 to $23.5/m³ $11,631 to 15,101

TOTAL ANNUAL ($1984) $13,461,000 to $16,931,000

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### SUMMARY OF PRESENT VALUE CALCULATIONS FOR BIOMASS GENERATION

**DISCOUNT RATE**

<table>
<thead>
<tr>
<th>SCENARIO 1 (8 YEARS)</th>
<th>8%</th>
<th>12%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LOW FUEL PRICE</strong></td>
<td></td>
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</tr>
<tr>
<td>$K = $32.06</td>
<td>$27.03</td>
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<tr>
<td>$O&amp;M = $70.55</td>
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<td>$T = $102.61 million</td>
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<td><strong>HIGH FUEL PRICE</strong></td>
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<td>$K = $32.00</td>
<td>$27.03</td>
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<td>$O&amp;M = $88.74</td>
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<td>$T = $120.80 million</td>
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</table>

<table>
<thead>
<tr>
<th>SCENARIO 2 (20 YEARS)</th>
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</thead>
<tbody>
<tr>
<td><strong>LOW FUEL PRICE</strong></td>
<td></td>
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</tr>
<tr>
<td>$K = $28.34</td>
<td>$23.89</td>
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</tr>
<tr>
<td>$O&amp;M = $39.64</td>
<td>$28.97</td>
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<tr>
<td>$T = $67.98 million</td>
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</tr>
<tr>
<td><strong>HIGH FUEL PRICE</strong></td>
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<td></td>
</tr>
<tr>
<td>$K = $28.34</td>
<td>$23.89</td>
<td></td>
</tr>
<tr>
<td>$O&amp;M = $46.96</td>
<td>$33.12</td>
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</tr>
<tr>
<td>$T = $75.30 million</td>
<td>$57.01 million</td>
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</tr>
</tbody>
</table>

1. Biomass fuel costs are derived from Forestal International's (1980) estimates for logging in the Stikine River watershed, inflated at 10% p.a. to 1984, allowance for 30% uncertainty in logging costs results in higher figure of $23.5/m³.

2. Scenario 1, based on conventional-fired generation utilizes fuel oil in conjunction with biomass to stabilize system and improve efficiency.

3. Scenario 1 system is based on a slightly modified version proposed for remote power generation in northern Manitoba, as documented in I.D. Engineering Company et al., (1984).

4. Excludes auxiliary oil and biomass costs.
The following schematic illustrates major components of the system presented in Omnifuel Gasification Systems, (1983) study, one option of which forms the basis for the system parameters and costs derived for this scenario.

GASIFIER/GAS TURBINE COMBINATION

Westinghouse 191 D. A summary description from Omnifuel Gasification Systems (1983) is as follows:

The turbine is a simple cycle, single shaft, cold end drive design. In other words, the prime power is taken from the air inlet end of the engine. The compressor section consists of 15 axial stages and has a combined compression ratio of 7.6:1. The casing is of a single horizontally split design. Multiple can-type combustors are canted between the compressor and turbine.

The turbine section consists of 5 axial stages with a maximum inlet temperature of 845°C.

The engine is mounted on a bedplate along with the integral lubricating oil reservoir, lube oil pumps, auxiliary gear unit, turning gear and starting equipment. An auxiliary skid contains the fuel controls, control air compressors, auxiliary motor controls, pressure switch and gauge panel.

Altogether the package measures 37 m long, 5 m wide and 4 m high and weighs 145,000 kg.
Site factor of 1.5 applied to items 1, 2, and 3 (as for small hydro) because costs quoted generally reflect purchase only. Scenario 1 did not use a site factor adjustment because costs reflect a remote northern Manitoba case history, costs are therefore of the same order as remote northern B.C.

COAL-FIRED ELECTRIC PLANT COSTS

Engineering, site, capital and operating cost parameters for small-scale remote coal-fired power generation are difficult to obtain under the best circumstances without detailed investigations. The following major component costs were estimated following lengthy discussions with representatives from Energy, Mines and Resources Canada (Jim Aylesworth and Phil Reed), Combustion Engineering (Evan Kennedy and Walter Zavadell), Westinghouse Corporation (Bill Watson and Stewart Roberts), Babcock-Wilcox (M. McCattum), and B.C. Hydro.

GENERAL ASSUMPTIONS:

1) In service date: 1990.

2) Installation Schedule: 2 years, costs apportioned 50% each year.

3) Coal Quality\(^1\): semi-antracite 29,600 kJ/kg (13,500 BTU/lb) low sulphur.

4) System Characteristics: Coal mined by Gulf Canada Resources, processed on site for sale to RED-CHRIS owners. Conventional coal-fired power generation on site, electricity transmitted to mine site 50 km NW.

5) Operation and Maintenance\(^2\): 10% of capital costs per annum.

6) Allowance for uncertainty of site specific and fuel specific costs\(^3\): 25%.

7) Coal price\(^4\): $91/tonne.
**SCENARIO 1 - RED-CHRIS PRODUCTION - 8 YEARS**

1) Boiler Characteristics - Combustion Engineering = 18 MW output. developing 200,000 lbs/hr. steam.

2) Turbine Characteristics - Westinghouse 18 MW output net--included are feed water/heater/condensor/cooling system/generator and switchgear.

3) Coal Consumption - 54,470 tonnes per annum.

4) Transmission Distance - 50 km @ 138 kV @ $90,000/km.

---

**SUMMARY OF COSTS ESTIMATED (X $,000)**

**Capital Costs:**

- 1) Boiler $7500
- 2) Turbine and Switchgear 13000
- 3) Coal Handling 4000
- 4) Transmission 4500
- 5) Access Improvement 1000

**SUBTOTAL $30 million**

6) Contingency @ 15% 4.5

**TOTAL CAPITAL $34.5 million**

**Annual Costs:**

- 1) Operation and Maintenance @ 10% 3.45 million
- 2) Coal Cost 4.96

**$1984 ANNUAL COST $8.35 million**
SCENARIO 2 - RED-CHRIS PRODUCTION - 20 YEARS

1) Boiler Characteristics - Combustion Engineering = 7.5 MW output
devloping 82,000 lbs/hr. steam.

2) Turbine Characteristics - Westinghouse 7.5 MW output net--included
are feed water/heater/condensor/cooling
system/generator and switchgear.

3) Coal Consumption - 21,786 tonnes per year.

4) Transmission distance - 50 km @ 60 kV @ $68,000/km.

SUMMARY OF COSTS ESTIMATED (X $.000)

<table>
<thead>
<tr>
<th>Capital Costs:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Boiler</td>
<td>$ 3500</td>
</tr>
<tr>
<td>2) Turbine and Switchgear</td>
<td>6800</td>
</tr>
<tr>
<td>3) Coal Handling</td>
<td>2000</td>
</tr>
<tr>
<td>4) Transmission</td>
<td>3400</td>
</tr>
<tr>
<td>5) Access Improvement</td>
<td>1000</td>
</tr>
<tr>
<td>SUBTOTAL</td>
<td>$16.7 million</td>
</tr>
<tr>
<td>6) Contingency @ 15%</td>
<td>2.51</td>
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<tr>
<td>TOTAL CAPITAL</td>
<td>$19.21 million</td>
</tr>
</tbody>
</table>

Annual Costs:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Operation and Maintenance @ 10%</td>
<td>1.92 million</td>
</tr>
<tr>
<td>2) Coal Costs</td>
<td>1.98</td>
</tr>
<tr>
<td>TOTAL ANNUAL ($1984)</td>
<td>$ 3.9 million</td>
</tr>
</tbody>
</table>
SUMMARY OF PRESENT VALUE CALCULATIONS FOR COAL-FIRED GENERATION

DISCOUNT RATE

<table>
<thead>
<tr>
<th>SCENARIO 1 (8 YEARS)</th>
<th>8%</th>
<th>12%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low Estimate</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K = $30.4</td>
<td>K = $25.82</td>
<td></td>
</tr>
<tr>
<td>O&amp;M = $43.8</td>
<td>O&amp;M = $31.57</td>
<td></td>
</tr>
<tr>
<td>T = $74.2 million</td>
<td>T = $57.39 million</td>
<td></td>
</tr>
<tr>
<td><strong>25% Allowance</strong></td>
<td>$93.0 million</td>
<td>$72.0 million</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SCENARIO 2 (20 YEARS)</th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>Low Estimate</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K = $16.69</td>
<td>K = $13.91</td>
<td></td>
</tr>
<tr>
<td>O&amp;M = $34.95</td>
<td>O&amp;M = $22.17</td>
<td></td>
</tr>
<tr>
<td>T = $51.64 million</td>
<td>T = $36.08 million</td>
<td></td>
</tr>
<tr>
<td><strong>25% Allowance</strong></td>
<td>$65.0 million</td>
<td>$45.0 million</td>
</tr>
</tbody>
</table>


5Allowance covers extraordinary items related to site specific engineering, materials, and perhaps environmental costs (W. Zavadell personal communication, 1985).
PUBLICATIONS (cont'd)
