Province of British Columbia
Ministry of Energy, Mines and Petroleum Resources
Hon. Anne Edwards, Minister

REFRACTORY MINERALS AND OPPORTUNITIES IN RELATED VALUE-ADDED PRODUCTS, BRITISH COLUMBIA, CANADA

by G.J. Simandl, D.H.G. Macgregor, M. Boucher,
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EXECUTIVE SUMMARY

Investment opportunities exist in British Columbia to develop refractory mineral deposits and to produce energy-intensive, value-added products derived from these minerals. Magnesite, silica, olivine, kyanite, andalusite, shale, pyrophyllite, graphite, dolomite, and brucite are among the refractory minerals found in the province. Magnesite and silica are produced in relatively large quantities.

Abundant and relatively inexpensive energy, especially hydroelectricity, is available in British Columbia. This is a key ingredient for the production of highly-priced, energy-intensive, value-added products. Silicon carbide, metallurgical and chemical grade silicon, magnesium metal, ferrosilicon, glass, synthetic and insulating mineral fibres are some of the large-tonnage products that have potential for development. Other relatively large-tonnage products of interest are caustic magnesia, dead-burned magnesia, magnesium hydroxide and sodium silicate.

There are also opportunities to exploit specialty refractory and advanced ceramic markets, such as synthetic Al-Mg spinel, fused magnesia, fused alumina, fused zirconia, synthetic mullite and fused silica. Plants capable of producing a variety of electrofusing products would allow the developer to serve several niche markets from the same installation. As well, a wide variety of extremely energy intensive materials used in the electronics industry, such as polysilicon, single silicon crystals and synthetic quartz, should not be overlooked.

British Columbia has a well developed transportation and industrial infrastructure, including several deep water ports. With ready access to Pacific Rim countries and competitive shipping costs to the Atlantic, the province is well situated to serve North American, Asian and European markets.

Investors and developers interested in producing refractory minerals and related-value-added products should consider British Columbia. The province has attractive energy costs, untapped mineral resources, industrial infrastructure and a good location to access some of the largest world markets.

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INTRODUCTION

Since the Second World War there has been continuous growth of the industrial minerals sector in British Columbia. Now there are 35 active industrial mineral producers in the province, excluding sand, gravel and construction aggregate operations.

This publication focuses on the production potential in British Columbia for refractory minerals, and electricity-intensive materials derived from them. The processing of imported raw materials into value-added products is also considered.

IMPETUS FOR DEVELOPMENT

Refractory minerals and related value-added products are singled out for special attention for a number of reasons:

- Large areas of British Columbia, largely unexplored for refractory minerals, offer excellent geological potential for the discovery of new deposits.
- Silica and magnesite mines are providing raw materials to local and export markets.
- Undeveloped deposits are already documented, some of which offer the potential for recovery of several products.
- The Province has a well-developed infrastructure with a number of deep water ports.
- Upgrading industrial mineral products is energy intensive. British Columbia is favoured with an abundance of relatively inexpensive energy sources, including coal, natural gas and, most importantly, hydro-electric power.
- Demand for high-performance, high-priced synthetic materials and fused refractories is increasing.
- International companies are seeking to diversify their sources of energy-intensive, value-added products.
- There is a potential for developing new markets for refractory minerals by promoting their use in non-traditional applications.

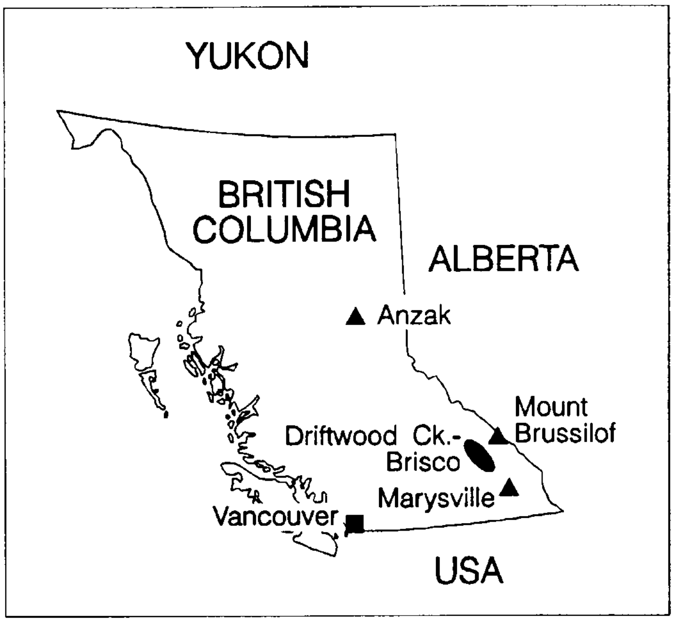

Figure 1. Selected magnesite occurrences.

TABLE 1
Chemical Analysis of Selected Magnesia Products of Baymag Mines Co. Limited

PRODUCT	FUSED MgO[1]		BAYMAG 30[2]		BAYMAG40[3]		BAYMAG96[4]		BAYMAG 58[5]	
	T	S	T	S	T	S	T	S	T	S
MgO*	97.3	>96.6	97.3	>96.5	97.3	>96.5	97.5	>96.5	97.1	>96.5
CaO*	1.7	<2.0	1.8	<2.3	1.8	-	1.7	<2.2	2	2.5
Fe_2O_3*	0.5	<0.7	0.6	-	0.4	-	0.5	-	0.5	-
Al_2O_3*	0.2	<0.3	0.1	-	0.2	-	0.1	-	0.1	-
SiO_2*	0.3	<0.4	0.2	-	0.3	-	0.2	-	0.3	-
LOI	-	-	2.2	-	5	-	-	-	0.2	-
iodine	-	-	30	-	40	-	-	-	-	-
number	-	-	-	-	-	-	-	-	-	-
Mg	-	-	-	-	-	-	-	-	58.6	>58.2

Physical Specifications Available Upon Request
Abbreviation: T = Typical S = Specified
[1] *Magnesia-carbon bricks and other high performance refractory applications where resistance to chemical attack is needed.*
[2] *Acid neutralizer in manufacturing of MgO compounds, water treatment agent, gas desulphurization and fuel additive.*
[3] *Applications where high reactivity is critical.*
[4] *Cellulose acetate, specialty refractories, Epsom salt, etc.*
[5] *Mainly in animal feed industry.*
* *Reported on loss free basis*

REFRACTORY MINERALS IN BRITISH COLUMBIA

The term "refractory mineral" is applied to those minerals that can withstand high temperatures in specific industrial environments and also to minerals that can be transformed into materials with refractory characteristics. Both natural and synthetic refractories, some of which are advanced ceramics, may have other commercial applications in addition to their traditional uses. For example, silicon carbide can be used as a refractory material, in the manufacture of specialty ceramics, in metallurgy, or as an abrasive.

Magnesite, silica, refractory clay and pyrophyllite are currently mined in British Columbia. The Province has an attractive olivine deposit and has good geological potential for graphite, andalusite, kyanite, and other refractory minerals (Simandl *et al.*, 1992).

Magnesite

There are more than 70 magnesite occurrences known in British Columbia (Grant, 1987). The most significant are sparry magnesite deposits hosted by sedimentary rocks but a few are associated with ultramafic rocks. The large, high-grade deposit at Mount Brussilof, in the Rocky Mountains northeast of Radium Hot Springs (Figure 1), accounts for most of Canada's current production of magnesite.

The Mount Brussilof deposit is hosted by Cambrian dolomites (Simandl and Hancock, 1991; Simandl *et al.*, 1991). The mine has been in production since 1982 and is operated by Baymag Mines Co. Limited (Schultes, 1986) a private company owned by Refratechnik GmbH of Germany. Raw magnesite from Mount Brussilof is processed into high-quality calcined and fused magnesia (Schultes, 1989) and has also been used as feedstock in the production of magnesium metal by the now defunct Magcan Ltd. in Alberta. Chemical analyses of some of Baymag's magnesia products are listed in Table 1 and analyses of typical ore are reported in Table 2. Physical properties may be obtained from the company or the British Columbia Ministry of Energy, Mines and Petroleum Resources.

Similar sparry magnesite deposits are located in the Brisco - Driftwood Creek area, west of Radium Hot Springs (Figure 1). Some are staked but none have been developed. The most recent drilling has been done by Canadian Occidental Petroleum Ltd. in 1990 on the Driftwood Creek deposit. Chemical analyses of some drill intersections are comparable to those of Mount Brussilof ore. All the deposits in the Brisco - Driftwood Creek area occur along evaporite horizons within the Precambrian Mount Nelson Formation (Simandl and Hancock, 1992). In general, they have lower magnesia and higher silica contents than Mount Brussilof ore, but have similar mineralogy and sparry texture. The most common impurities are quartz, chert and dolomite with talc, calcite, pyrite, iron oxides and clay minerals in trace amounts. Chemical analyses of surface samples from seven undeveloped deposits (Driftwood Creek, Topaz Lake, Red Mountain, JAB, Clelland Lake, Dunbar Creek and Botts Lake) are listed in Table 2. These deposits have equivalent or higher grades than magnesite deposits currently mined in Europe.

Magnesite occurrences are also known in Precambrian sedimentary rocks of the Cranbrook Formation. At Marysville (Figure 1), between Cranbrook and Kimberley, magnesite-bearing rocks have been traced for a distance of 8 kilometres. These deposits were extensively explored by Cominco Ltd. in the late thirties. Work then included test pitting and driving several adits, with bulk sampling and diamond drilling done more recently. The company still holds the Crown-granted claims covering most of the showings. The Marysville magnesite beds are similar to those in the Brisco-Driftwood area although overall grades are lower. Their mineralogy varies considerably across stratigraphy. The central portions of the magnesite beds are purest (Hancock and Simandl, 1992). The principal impurities are dolomite, quartz (1-20%), chlorite (0-2%), sericite (0-1%) and pyrite (trace). Analyses from the purest portions are reported in Table 2.

All the deposits mentioned thus far are near well developed road and rail networks in southeastern British Columbia. A significant prospect is also known in the northern Rocky Mountains on Chuyazega Creek near Anzac, 120 kilometres northeast of Prince George (Figure 1). The mineralogy and lithology are similar to the Mount Brussiloff deposit (Hancock and Simandl, 1993). Typical analyses from surface samples are reported in Table 2. Initial exploration was undertaken by MineQuest Exploration Associates Ltd. on behalf of Norsk Hydro between 1989 and 1991 (Gourlay, 1991).

The economic potential of undeveloped magnesite deposits in British Columbia is improving with the increase in non-refractory uses for magnesite and magnesia such as environmental appli-

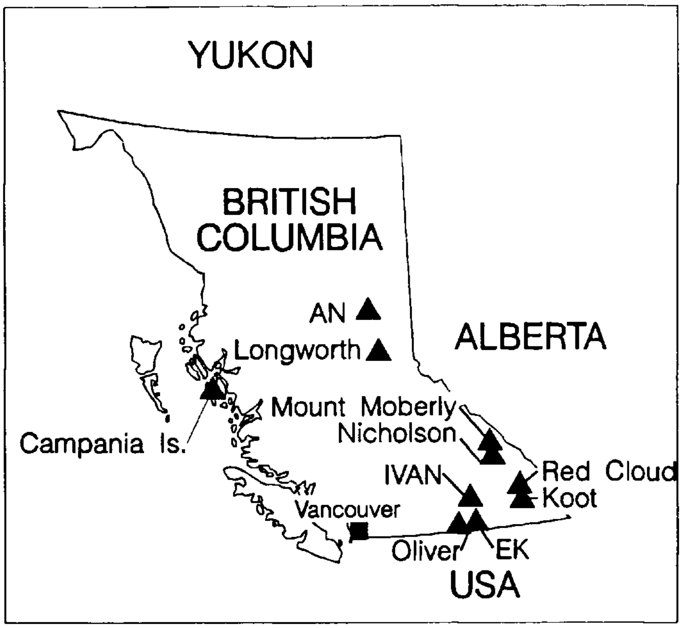

Figure 2. Selected silica occurrences.

TABLE 2
Chemical Composition of Surface Samples from Sedimentary-hosted Magnesite Deposits

DEPOSIT	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	TOTAL
Anzak	0.44	<0.01	0.21	1.16	0.02	43.79	3.14	0.01	0.01	1.04	50.36	100.19
	0.39	<0.01	0.08	0.76	0.02	34.23	16.70	0.01	0.01	0.82	48.95	101.98
	2.23	<0.01	0.11	0.98	0.02	48.99	0.72	0.01	0.01	0.86	50.01	98.95
Driftwood Creek	7.32	0.09	1.01	0.75	0.01	39.57	0.60	0.27	0.04	<0.01	47.61	97.28
	2.05	<0.01	<0.01	0.86	0.02	37.27	8.08	0.09	0.00	<0.01	50.02	98.42
	15.97	<0.01	0.08	0.52	0.01	38.62	0.10	0.04	0.03	<0.01	43.56	98.95
Topaz Lake	7.11	0.02	0.51	1.37	0.02	42.16	0.61	0.02	0.00	<0.01	46.68	98.51
	7.43	<0.01	0.20	1.34	0.02	41.03	0.31	0.02	0.01	<0.01	48.27	98.65
	4.18	0.03	0.70	1.60	0.02	43.00	0.32	0.02	0.15	<0.01	49.41	99.44
Red Mtn.	10.64	0.01	0.52	1.64	0.03	38.74	0.92	0.10	0.03	<0.01	45.54	98.18
	8.09	0.01	0.33	0.82	0.01	40.14	0.32	0.02	0.03	<0.01	47.91	97.69
JAB	4.67	<0.01	0.13	1.35	0.02	41.99	0.57	0.04	0.00	<0.01	48.66	97.45
	5.56	<0.01	0.13	1.27	0.02	42.55	0.52	0.04	0.01	<0.01	47.37	97.49
	4.43	0.01	0.20	2.02	0.03	41.85	0.35	0.04	0.00	<0.01	48.60	97.54
Clelland Lake	2.80	<0.01	0.12	1.66	0.03	41.12	1.14	0.05	0.01	<0.01	50.36	97.31
Dunbar Creek	2.53	<0.01	0.20	2.11	0.04	41.48	1.36	0.04	0.02	<0.01	50.30	98.10
Botts Lake	3.62	<0.01	0.03	0.27	0.01	38.82	6.68	0.09	0.08	<0.01	48.85	98.47
Marysville	2.59	0.02	0.64	1.71	0.03	46.00	0.92	<0.01	0.01	<0.01	49.50	101.44
	5.90	0.04	0.84	1.12	0.02	43.42	1.09	<0.01	0.03	0.28	47.28	100.03
	3.59	0.05	0.92	0.72	0.01	45.11	1.02	<0.01	0.15	0.02	49.02	100.62
Mt. Brussilof *	<0.01	<0.01	<0.01	0.35	0.01	48.00	0.82	0.01	0.03	<0.02	51.96	101.23
	0.10	<0.01	<0.01	0.38	0.01	47.00	1.41	<0.01	0.02	0.03	51.44	100.42
	<0.01	<0.01	<0.01	0.37	0.01	48.12	1.02	<0.01	0.01	0.01	51.86	101.44
	<0.01	<0.01	<0.01	0.51	<0.01	47.74	0.85	<0.01	0.01	0.02	51.88	101.06
	<0.01	<0.01	<0.01	0.42	0.01	47.89	0.87	0.00	0.00	0.01	52.02	101.31

* *Fresh samples from the excavation*

cations (Bartha and Schultes, 1993), more use of magnesia-based refractories in response to technological changes in steel making and increased use of magnesium metal in the automotive industry. Environmental applications of magnesite-derived magnesia products are becoming particularly significant.

The introduction of export licenses in China for MgO resulted in higher prices in 1994 (Industrial Minerals, 1994).

Silica

British Columbia has large untapped resources of silica classifiable as massive "lump" quartzite, friable quartzite, quartz veins and pegmatites (Foye, 1987). The Mount Wilson quartzite is the largest single resource of silica in the province. The quartzite is a Middle to Upper Ordovician unit that extends from Golden, approximately 200 kilometres southwest to Fernie. The thickness decreases from 300 metres at Golden to 60 metres near Fernie (Norford, 1969). The Mount Moberly and Nicholson (Hunt) deposits, located within this unit, are currently in production. Other prospects include the Red Cloud and Koot occurrences and are located on Figure 2. Typical chemical analyses are listed in Table 3.

The Nicholson (Hunt) silica quarry, 11 kilometres southeast of Golden (Figure 2), is in massive quartzite of the Ordovician Mount Wilson Formation. The quarry is owned by Silicon Metaltech of Seattle, Washington, and operated by Bert Miller Contracting Ltd. of Golden. Annual production varies between 30 000 and 60 000 tonnes (Foye, *ibid.*); the ore contains less than 0.15% non-silica material (Table 3). After crushing, washing and screening on site, lump silica is shipped as feedstock for production of silicon and ferrosilicon at a plant in Wenatchee, Washington. Production could be increased if new silicon or ferrosilicon plants were established in British Columbia.

The nearby Moberly Mountain silica operation is owned and operated by Mountain Minerals Company Ltd. Two ore types are currently mined. The first is a uniform, massive, silica-cemented friable quartz arenite and the second, recently introduced to market, is massive quartzite. Both are from the Mount Wilson Formation and ore sample analyses are listed in Table 3. In 1985, ore reserves were estimated at 10 million tonnes of friable quartz arenite and 50 million tonnes of quartzite. The bulk of friable quartz arenite production is sold to the container-glass manufacturing industry but the quarry also supplies silica for a variety of other applications including blasting, traction and foundry sands. The massive quartzite is similar in character to that of the Nicholson deposit and is suitable for silicon metal and ferrosilicon production.

Other high-purity quartz arenite and quartzite occurrences include the Longworth deposit in the Silurian Nonda Formation and the AN and EK showings. Vein deposits include the Oliver, Ivan and Campania showings (Figure 2). Typical chemical analyses for these deposits are listed in Table 3.

Quartz veins in the Oliver Plutonic Complex, near the town of Oliver in the southern Okanagan Valley, have been mined for their gold, base metal and silica content. The veins vary from 0.3 to 4 metres wide, with the wider veins invariably cutting the porphyritic quartz monzonite phase of the complex. Production from one vein has been used in the manufacture of ferrosilicon and quartz from other veins has been used as flux in the Trail smelter. Small-scale production took place at the Ivan deposit, 6 kilometres west of Armstrong. Some of the quartz mined was used for manufacturing synthetic quartz crystals (Foye, *ibid.*).

As a group, the silica deposits in British Columbia offer excellent potential for the production of a variety of value-added materials including, fibre-glass, various glass products, ferrosilicon, silicon carbide, metallurgical grade silicon and sodium silicate. A continuing trend towards the use of chemical-thermal-mechanical pulp processes in North America may substantially increase the use of silica sand to produce sodium silicate. Currently the sodium silicate used in British Columbia's pulp mills is imported from the United States as briquettes and liquefied at the National Silicates Ltd. plant at Parksville on Vancouver Island. Some of the many and varied secondary and tertiary silica products are fused silica, silicon nitride, single and polysilicon crystals, silanes, silicones, microsilica, as well as aluminum, calcium and potassium silicates, and precipitated silica.

Olivine

Olivine is another industrial mineral currently imported into Canada that is benefiting from expanding markets in new applications. It is traditionally used as a foundry sand in metal casting and as a non-precalcined material for steel making. Olivine is also finding new uses as a heat-exchanger filler, an environmentally friendly blasting sand and as heavy aggregate and marine ballast

TABLE 3: Analyses of Silica Samples

MAJOR ELEMENTS (weight %)

DEPOSIT	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	MnO	LOI	S	P	Note
MOBERLY (friable)	99.61	0.07	0.13	0.005	—	—	—	—	—	0.010	—	—	*
MOBERLY (friable)	99.64	0.06	0.10	0.005	—	—	—	—	—	0.020	—	—	*
MOBERLY (friable)	99.67	0.02	0.06	0.060	0.020	0.01	0.02	0.01	0.000	0.120	—	—	**
MOBERLY (lump)	98.0	0.05	0.33	0.0150	<0.001	0.0046	0.07	0.02	<0.001	0.10	—	0.00067	#
MOBERLY (lump)	98.2	0.08	0.16	0.0075	<0.001	0.0038	0.03	0.01	<0.001	0.10	—	0.00048	#
MOBERLY (lump)	98.9	0.04	0.16	0.1040	<0.001	0.0027	0.03	0.01	<0.001	0.20	—	0.00057	#
MOBERLY (lump)	98.4	0.06	0.33	0.0159	<0.001	0.0053	0.05	0.02	<0.001	0.15	—	0.00063	#
HUNT (NICHOLSON)	98.76	—	1.13	nil	—	—	—	—	—	—	—	—	***
HUNT (NICHOLSON)	97.94	—	1.25	nil	—	—	—	—	—	—	—	—	***
HUNT (NICHOLSON)	98.24	—	0.85	nil	—	—	—	—	—	—	—	—	***
HUNT (NICHOLSON)	99.85	0.04	0.10	<0.050	<0.050	<0.10	<0.10	<0.05	<0.010	0.320	—	—	#
HUNT (NICHOLSON)	99.90	0.04	0.10	<0.050	0.050	<0.10	<0.10	<0.05	<0.010	0.310	—	—	#
RED CLOUD	98.56	0.12	0.65	0.050	—	—	—	—	—	0.000	—	—	*
LONGWORTH	99.40	<0.05	0.18	<0.030	<0.030	<0.04	0.06	<0.04	0.003	1.000	—	—	##
LONGWORTH	98.84	0.04	0.20	<0.030	<0.030	<0.03	0.05	<0.04	<0.002	<0.100	—	—	##
LONGWORTH	98.76	<0.04	0.16	<0.030	<0.030	<0.04	0.05	<0.04	<0.002	0.300	—	—	##
LONGWORTH	98.76	<0.04	0.17	<0.030	<0.030	<0.03	0.05	<0.04	<0.002	0.200	—	—	##
LONGWORTH	98.91	<0.04	0.19	<0.030	<0.030	<0.04	0.07	<0.04	<0.002	<0.100	—	—	##
LONGWORTH	99.35	<0.04	0.21	<0.030	<0.030	<0.03	0.06	<0.03	<0.002	<0.100	—	—	##
LONGWORTH	99.32	<0.04	0.20	<0.030	<0.030	<0.03	0.06	<0.03	<0.002	<0.100	—	—	##
LONGWORTH	99.30	<0.04	0.25	<0.030	<0.030	<0.03	0.07	<0.03	<0.002	0.300	—	—	##
AN	99.43	0.09	0.08	0.011	0.000	—	—	—	—	0.180	—	—	++
EK	99.00	0.06	0.04	<0.030	<0.020	—	—	—	—	0.100	—	—	+++
EK	99.90	0.11	0.10	0.350	<0.020	—	—	—	—	0.500	—	—	+++
IVAN	99.56	0.08	0.27	0.056	0.000	—	—	—	—	0.000	—	—	=
CAMPANIA	99.73	0.07	0.05	<0.030	<0.020	<0.03	0.02	<0.04	<0.002	0.800	—	—	###
CAMPANIA	99.84	<0.04	0.06	<0.030	<0.020	<0.03	0.01	<0.03	<0.002	0.200	—	—	###
KOOT Average	98.90	0.25	0.40	0.05	0.05					0.29	0.04	0.01	@
KOOT Std. Dev.(n - 1)	0.54	0.11	0.11	0.13	0.10					0.18	0.02	0.00	

TRACE ELEMENTS (ppm)

DEPOSIT	Ag	Al	Ba	Ca	Cd	Co	Cu	Fe	K[1]	Li	Mg	Mn	Mo	Na[1]	Ni	P	Sr	Ti	Zn	Zr
MOBERLY	2	370	3	130	<0.3	<0.3	<0.5	100	180	4	51	2	<1	32	<2	12	2	56	2	6
MOBERLY	3	370	3	140	<0.3	<0.3	<0.5	93	180	4	55	2	<1	31	<2	12	2	56	2	6

analysis by ICP; [1] *by AAS* *from General Electric Corporate Research and Development: GEL-Quartz Products Department, 1993.*

*	*Grab sample*	**	*Washed sample*	***	*Random samples of equal sized chips*
#	*Stockpile of processed material*	##	*Chip samples across 10 m.*	###	*"Clean quartz" samples*
+++	*Chip sample*	—	*Not analysed*	=	*Loose muck*
++	*Average based on 5 drill holes; no road or rail access to site*				
@	*average of 25 analyses of drill core sections over 20-metre interval*				

TABLE 4: Greensand Properties Before and After Each Trial

Casting Property	Sand Type	Casting Trial Number 1	2	3	4	5	
Sand Properties Before Each Casting Trial:							
Compactability, %	IMC Olivine[+]	44	45	48	44	49	
	Grasshopper Mountain	49	47	45	45	49	
Moisture, %	IMC Olivine	2.15	2.15	2.24	2.20	2.15	
	Grasshopper Mountain	2.16	2.21	2.14	2.13	2.23	
Density, grams	IMC Olivine	195	195	193	192	190	
	Grasshopper Mountain	186	185	185	185	183	
Permeability, AFS units	IMC Olivine	200	195	210	215	228	
	Grasshopper Mountain	249	240	240	243	253	
Green Compressive	IMC Olivine	30.0	27.1	29.0	30.2	28.9	
Strength, psi	Grasshopper Mountain	25.7	25.2	28.0	29.6	28.6	
Clay Additions, %	IMC Olivine	6.0	0.1	0.1	0.0	0.0	
	Grasshopper Mountain	6.0	0.3	0.15	0.05	0.2	
Methylene Blue Clay, %	IMC Olivine	6.1	6.1	6.3	5.8	5.8	
	Grasshopper Mountain	6.1	6.1	6.2	6.0	5.8	
Mold Hardness, B scale	IMC Olivine	88	88	88	90	88	
	Grasshopper Mountain	88	88	90	90	88	
AFS Grain Fineness	IMC Olivine	42.7	-	-	-	-	*50.6
Number	Grasshopper Mountain	44.3	-	-	-	-	*54.5
After Casting Trials							
Moisture, %	IMC Olivine	0.85	0.82	0.94	0.81	N/D	
	Grasshopper Mountain	0.93	0.83	0.98	0.85	N/D	
Methylene Blue Clay, %	IMC Olivine	5.9	5.9	6.1	6.1	N/D	
	Grasshopper Mountain	5.7	5.9	5.6	5.8	N/D	
AFS Clay, %	IMC Olivine	N/D	N/D	N/D	N/D	8.96	
	Grasshopper Mountain	N/D	N/D	N/D	N/D	8.48	
Additional Tests							
Acid Demand	at	pH 5	pH 7				
	IMC Olivine	ml	9.6	8.5			
	Grasshopper Mtn.	ml	33.6	30.5			
Loss on Ignition	at	500 C	700 C	975 C			
	IMC Olivine	%	0.55	1.25	1.51		
	Grasshopper Mtn.	%	0.90	1.82	1.83		

* *After fifth trial and after washing for AFS Clay test. (after Whiting et al., 1987).*
\+ *IMC 50 foundry sand was used as a reference material.*

TABLE 5: Scab Block Casting

Casting Property	Sand Type	Casting Trial Number 1	2	3	4	5
Surface Finish	IMC Olivine	3	3	3	3	2
	Grasshopper Mountain	3	3	3	3	2
Scabbing	IMC Olivine	1	1	1	1	1
	Grasshopper Mountain	1	1	1	1	1
Burn On	IMC Olivine	2	2	2	2	2
	Grasshopper Mountain	2	2	2	2	2
Erosion	IMC Olivine	2	2	2	2	2
	Grasshopper Mountain	2	2	2	2	2
Penetration	IMC Olivine	2	2	2	2	2
	Grasshopper Mountain	2	2	2	2	2

Note: Each casting was rated on a scale of 1 to 5 where: 1 = good and 5 = bad. tests (source: Whiting et al., 1987).

(Simandl *et al.*, 1992). A relatively new market is the served by the production of olivine-based panels used to manufacture silo-type burners for incinerating wood waste. These burners are more environmentally sound than the traditional beehive waste burners. Silo-type, olivine-panel burners can also be equipped to generate electrical power which can partially offset the cost of waste disposal. The olivine-based panels used in British Columbia are imported from the United States. The market within British Columbia is uncertain due to proposed new environmental regulations on wood burners. However, there is potential for sales to developing countries, such as Brazil where silo-type burners are expected to be introduced. Recent studies by the U.S. Bureau of Mines indicate that addition of olivine to chromium-bearing waste slags reduces leachability of chromium by 80% (Kilan and Shah, 1984). Olivine may be used in the future for disposal of chrome-based slags.

Thirty kilometres northwest of Princeton (Figure 3), three zones of fresh, olivine-rich rock (dunite) have been investigated on Grasshopper Mountain (Hancock *et al.*, 1991; Hora and White, 1988; White, 1987). Findlay (1963, 1969) mapped and sampled the Tulameen Ultramafic Complex. Contoured loss-on-ignition values of less than 2% outlined a zone of fresh dunite within the core of the complex. Three locations have been found that have olivine of foundry sand grade. Preliminary tests indicate the olivine sand has casting properties comparable to IMC olivine (Table 4). The olivine from the Tulameen Complex (Table 5) is high in magnesia and compares favourably with other olivine from around the world (Szabo and Kular, 1987; Whiting *et al.*, 1987). A potential developer could attempt to supply all segments of the olivine market in order to maximize the size of the operation.

Refractory Clays, Pyrophyllite and Diatomite

There are a number of clay and shale deposits (Figure 3) of potential commercial quality in British Columbia (Brady and Dean, 1964; Ries, 1915). At present the only production of clay for refractory brick is by Clayburn Industries Ltd. The deposit at Sumas Mountain in the Fraser Valley, produces for their plant in nearby Abbotsford.

Clayburn Industries Ltd. also uses small quantities (140 tonnes in 1990) of pyrophyllite from the Pyro claims near Princeton and diatomaceous earth from Quesnel. Other raw materials used in the refractories, such as bauxite and ball clay, are imported. The raw materials are used to manufacture high-alumina (50-85% Al_2O_3) brick, fireclay brick, light-weight, machine-ground insulating brick, castables, plastic insulation, brick and mortars. The major products marketed by Clayburn Industries are acid refractories used in aluminum and base metal smelting, oil refining, incinerators, lime kilns and other industrial furnaces, and in the pulp and paper industry. Much of Clayburn's production is exported.

Other potential refractory clay deposits in the Lower Mainland area include a mudstone 15 to 30 metres thick exposed on Blue Mountain, 20 kilometres northwest of Mission on the Fraser River, and a number of brown and dark grey mudstone and claystone beds intersected in drill holes during exploration for residual kaolin deposits in the Lang Bay area near Powel River, northwest of Vancouver. The Lang Bay claystone beds are classified as medium to high-duty fireclay (Hora, 1989). Tests on samples of the Blue Mountain mudstone indicate that it is less refractory than the material mined at Sumas Mountain (Ries, *ibid.*).

On Vancouver Island, a claystone bed with good refractory properties (pyrometric cone equivalent of 31.5) is associated with the No. 1 coal seam at the Quinsam colliery near Campbell River (Hora, 1989). Several small or poorly known pyrophyllite occurrences are described or listed by MacLean

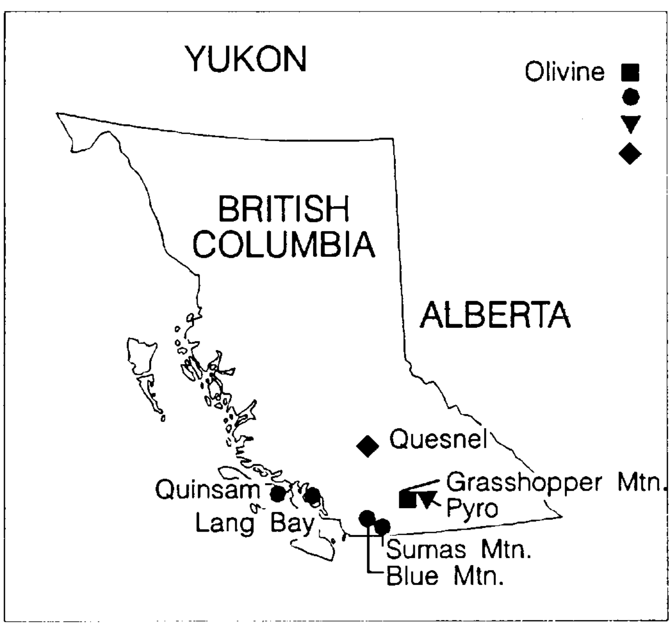

Figure 3. Selected olivine, clay, pyrophyllite and diatomaceous earth occurrences.

TABLE 6
Summary of Published Information on Kyanite, Andalusite and Sillimanite

	— Aluminosilicates —			Possible
Area	Kyanite	Sillimanite	Andalusite	By-products
Southern Shuswap		20 - 25%		<30% Gr, (Mi?)
Revelstoke - Big Bend	20 - 30%			(Mi?)
Canoe River	20 - 25%			15 - 20% Gr, (Mi?)
Hope-Yale Settler Schist	23%(L)	24% (L) 15 (P)		<30% Gr, (Mi?)
Hope-Yale (Breakenridge Fm.)	<40%		Minor	<50% Gr
Hope-Yale (Cairn Needle)	15% (av.)			20% (av.) Gr, (Mi?)
Kwinamass Peek		<50%		15 - 20% Gr, (Mi?)
1 km east of Kwinitsa		5 - 30%		5 - 30% Gr
Hawksbury Island	<20%			<20% Gr
Valentine Mountain			?	Gr, St

Abbreviations: Gr - garnet, P - prismatic, St - Staurolite, L - Locally, av. - average, (Mi?) - type of mica is not specified ***(Pell, 1988)***

(1988). The most promising of these require additional investigation to determine if they have economic potential. One of the deposits conveniently located on the west coast of Vancouver island has been investigated (1994) by New Global Resources Ltd.

There are several documented diatomite occurrences in the province. The most economically interesting are located between Kamloops and Quesnel in the southern Interior (Hora, 1984). Recent experiments indicate that diatomite can be used to manufacture synthetic mullite. This may improve the economic assessment and value of some diatomite occurrences. Diatomite is not limited to refractory uses. Major applications include filtration/filter aids, specialty fillers, anti-blocking agents and mild abrasives.

Kyanite, Andalusite, Sillimanite and Mullite

Anhydrous aluminosilicates, commonly developed in amphibolite facies metamorphic rocks, are widespread in British Columbia. They include 50 kyanite, 23 sillimanite and 8 andalusite localities (Pell, 1988). Some of these occurrences also contain garnet and mica. The majority are in metapelitic schists of the Coast and Omineca crystalline belts (Figure 4). There is also a significant potential for contact metamorphic andalusite deposits locally associated with porphyry copper systems. The mineralogy and grades of a few selected occurrences are summarized in Table 6. The crystal size of the aluminosilicates varies from a few millimetres to several centimetres. Sillimanite commonly occurs in the form of fibrolite, which is difficult to extract, but prismatic sillimanite is also reported (Pell, *ibid.*).

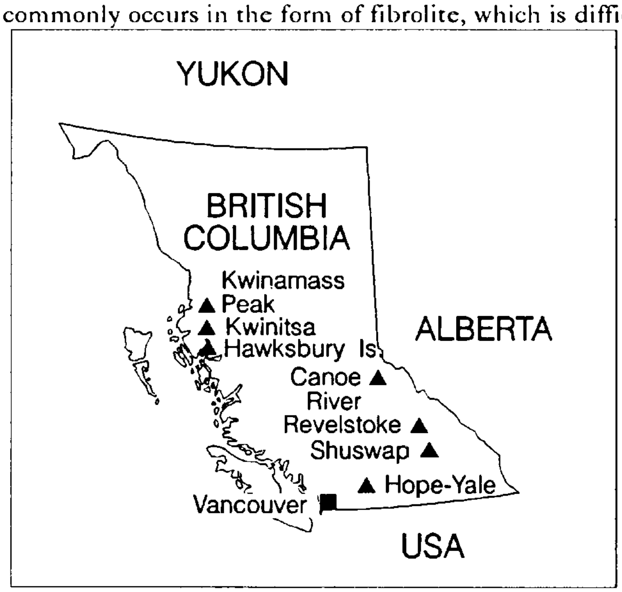

Figure 4. Selected kyanite family mineral occurrences.

The most important industrial use of aluminosilicates is in refractories, but new applications are being developed in the manufacture of paper, paint, brake linings, welding rods, catalytics and filters. Andalusite is preferred in Europe and Japan as it requires no pre-firing before use. The greatest portion of world andalusite production comes from South Africa. Political uncertainties in South Africa could force major trading companies to investigate alternative deposits, including those in British Columbia. Standard mullite is a value-added product made by calcining naturally occurring aluminosilicates, usually kyanite. High-quality synthetic mullite is produced by fusing Bayer process alumina with pure silica sand.

Kyanite prospects, where kyanite coexists with garnet and mica, may also be worthwhile exploration targets. Typical garnet abrasive currently sells for US$160 to $220 per tonne. Sketchy geological descriptions rarely specify the variety of mica associated with garnet and aluminosilicates, however light coloured, commercial mica concentrates are currently valued at US$200 to $1000 per tonne depending on the level of processing.

Graphite

More than 30 occurrences of graphite are reported in British Columbia. Few have ever been investigated or described in the literature. The most promising areas for crystalline, flake graphite showings are located within the Coast plutonic complex and the Omineca crystalline belt. Several reported showings are suggested for preliminary field examination, based on published descriptions (Figure 5).

Figure 5. Selected graphite occurrences.

The AA graphite prospect, located on tidewater at the head of South Bentinck Arm, occurs in a retrograde, granulite facies, metasedimentary roof pendant within granitic rocks of the Coast plutonic complex. Assays indicate total carbon content in the range of 2.98 to 17.9%. The size and shape of the graphitic zone is not known (Marchildon *et al.*, 1993). This or other amphibolite or granulite facies metasedimentary roof pendants have excellent potential to host economic graphite deposits.

The Skeena showing is hosted by amphibolite and biotite-hornblende gneisses of the Coast Plutonic Complex and is reported to contain 3% graphite across a width of 120 metres (Clothier, 1922). A few grab samples of vein material with gold valnes up to 3 grams per tonne were reported in 1922 but have not been confirmed. The Payroll showing, occurs in amphibolitic rocks of the Coast Complex. It is an apparently concordant graphitic unit 3 to 4.5 metres thick (Clothier, 1921). The Mon occurrence reportedly contains flakes of crystalline graphite disseminated in marbles, calcsilicates and biotite schists of the Wolverine Metamorphic Complex in north-central British Columbia. Sillimanite was observed in metapelitic rocks (F. Ferri, 1994, personal communication). Assays reported by Halleran (1985) suggest grades in excess of 4% graphitic carbon.

These and other graphite showings indicate geological environments where economic concentrations of crystalline, flake graphite may occur and warrant further investigation. No occurrences of microcrystalline graphite in metamorphosed coal seams have been reported in British Columbia, but meta-anthracite seams are known. Systematic exploration for microcrystalline graphite in metamorphosed coal beds has not been done in British Columbia.

Quinto Mining Corporation is attempting to develop a gold, graphite and sericite deposit, 37 kilometres east of Vernon. The microcrystalline graphite is intergrown with mica and cannot be upgraded to a marketable graphite concentrate. Therefore the company is examining the possibility of marketing a muscovite-graphite product derived from processing gold ore (Schiller, 1993).

Other Minerals

Another mineral with known refractory applications, but not produced for this purpose in British Columbia, is dolomite (Fischl, 1992). Although several tidewater dolomite occurrences are documented, no systematic study of the possible use of this material for refractories has been done. Occurrences of zircon, chromite (Hancock, 1991) and brucite (Grant, 1987) are also reported in the province. Magnesia-bearing tailings are located at the site of former Cassiar asbestos mine. Zircon, an accessory mineral in many igneous rocks, is commonly recovered from beach placer deposits raising the possibility of byproduct recovery from placer gold mining operations.

VALUE-ADDED, ELECTRICITY-INTENSIVE MINERAL PRODUCTS

BRITISH COLUMBIA'S POTENTIAL

Industrial minerals are an increasingly significant component of international trade with overseas shipping a critical element. Due to limited local markets, most new industrial mineral developments in British Columbia must be competitive in the global marketplace. One key to success lies in adding value to traditional commodities by further processing and refining. Some of the traditional methods used in processing and upgrading raw industrial mineral commodities are listed in Figure 6. The resulting products can command prices double, triple or more, than that of the raw material. These value-added products can often be shipped worldwide.

Successful plants producing large tonnages of energy-intensive products have most often been established in areas with low energy costs. For example, Alcan imports alumina to its Kitimat aluminum smelter on the Province's north coast because it can use inexpensive hydro-electric power at that site.

British Columbia has attractive energy prices and deep sea ports. In addition, it is strategically located to serve Asian and western North American markets. Through economies of scale in off-shore shipping, as described by Crouch (1993), it can also be competitive in Europe. Due to the abundance of locally generated and competitively priced electricity, and a relatively small population, British Columbia is expected to maintain competitive energy prices. Densely populated countries face greater pressures to reduce the proportion of electrical energy available for industrial use in favour of residential and commercial purposes. As well, countries with existing plants based on obsolete or polluting technology will increasingly be at a competitive disadvantage (Horst, 1993) and, as a consequence, will probably experience declining sales.

Currently, there is a worldwide rationalization of the production of energy-intensive products. Companies are tending to relocate plants or production to countries offering the most favourable business climate. This restructuring is mainly due to the increasing acceptance of high-performance refractories, and an instability in light-metal markets which is largely a result of major political change in Central and Eastern Europe. The recent global economic slowdown and the emergence of China as a competitive supplier are also contributing factors.

Changes in market conditions, development of new technologies, depletion of resources in some traditional producing areas, rapid escalation of industrial energy costs in some European countries (Platt's Metals Week, 1994a), unreliable power supplies in parts of northwestern USA (Platt's Metals Week, 1993), and political instability in other countries suggest that it may be timely to evaluate the feasibility of producing these materials in British Columbia.

There is an opportunity for new facilities in the province to produce target-selective, energy-intensive products. Electrofusing facilities can be designed to produce a variety of products for refractory niche markets as demonstrated by a plant under construction at Kalamassery, Kerala,

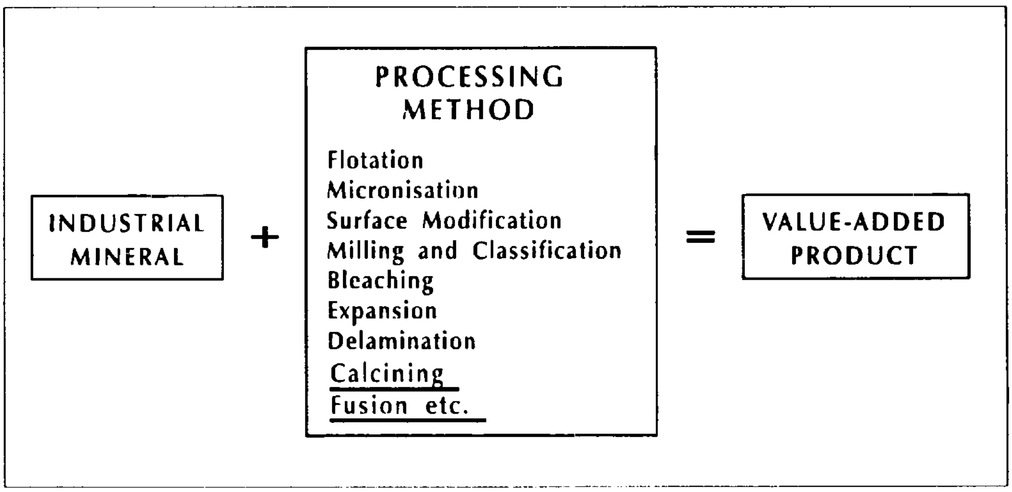

Figure 6. Value-added concept.

India, by Carborundum Universal Ltd. It will have an annual capacity of 12 000 tonnes of white fused alumina or 8 000 tonnes of brown fused alumina. The key feature is that its design is flexible and allows the plant to also produce fused magnesia and fused zirconia products (Industrial Minerals, 1993).

British Columbia is well positioned to serve such specialty markets as it can utilize both locally produced mineral resources and widely available low-cost imported materials. High unit-value electrofused materials produced in the Province could be traded internationally. Targeting of multiple markets allows increased diversity in product lines and higher plant capacity. This is the key to long life in quickly evolving fields such as high-performance refractories for the steel industry. Similar rapid changes are taking place in the advanced ceramics field.

A variety of electricity-intensive products could be produced in British Columbia. Those derived from silica and magnesite are of particular interest. Both minerals are mined and sold in the province. They are used to produce energy-intensive products at plants outside of the province. Furthermore, large undeveloped deposits of these minerals are locally available.

Low-cost raw materials, that are not locally produced, can be imported from overseas, upgraded and subsequently exported. The low cost and ready availability of imported raw materials, such as bauxite or alumina, may play a key role in any decision-making concerning the installation of a modern electrofusing plant in British Columbia. Such imports may be required to allow specialized electrofusing plants to serve multiple niche markets.

ELECTRICITY-INTENSIVE MATERIALS

Electricity-intensive, value-added industrial products can be divided into four basic categories (Table 7), based on the production capacity of a typical plant and to some extent on energy consumption per tonne. The table is not complete and its main objectives are to channel discussion and better focus the concepts covered in this paper.

TABLE 7
Selected Electricity-intensive Products.

Group I	Group II	Group III	Group IV -
High tonnage	**Small tonnage**	**Limited tonnage**	**Other Products*** **
Typical production capacity: 30 000 to 50 000 tpa	Typical production capacity: 5000 to 30 000 tpa	Typical production capacity: 5 000 tpa	Tonnage & power consumpiton are product specific.
Typical power consumption: 8000 to 13 500 kWh/t	Typical power consumption: <5000 kWh/t	Typical power consumption: highly variable	
- Ferrosilicon	- Fused magnesia	- Al-Mg spinel	- Polysilicon #
- Silicon metal	-abrasive grades	- Synthetic mullite	- Single silicon crystals #
a) chemical grade	-refractory grades	- Zirconia-mullite	- Synthetic diamonds #
b) metallurgical grade	-electrical grades	- Fused zirconia	- Synthetic quartz #
- Silicon carbide	- Fused silica:	- Magnesia-spinel brick	- Sinterable silicon carbide #
- Mg metal *	-optical & electronic grades	- AZS fused shapes	- Silicon nitride #
- Al metal *	-refractory grade	- AZS brick	- Composites #
	- Fused alumina *	- Zirconium metal	- Ceramic fibres & whiskers #
	-brown		- Boron nitride #
	-white		- Titanium diborite #
	-pink		- Rock wool **
			- Glass**
			- Fibreglass **
			- Sodium silicate **
			- Precipitated silica **

* *Some aluminum magnesium and fused alumina plants have significantly higher capacities than those listed above.*
** *High or small tonnage production capacity, moderately energy- intensive products*
# *"lab scale" or less than several thousand tonnes/year production capacity*
*** *Steel derived from mini-mills using electric arc furnace technology, and plasma coating advanced ceramics are covered by previous studies (Akhtar and Ross, 1990)*

Group I: High Tonnage Products (Silicon, Ferrosilicon, Silicon Carbide, Aluminum and Magnesium)

This group consists of materials which are typically produced on a large scale (Table 7). The capacity of a typical plant that produces these materials is in the range of 30 000 - 50 000 tonnes per year (tpa), although the annual capacity of plants producing aluminum and magnesium commonly exceed this range. This size of production requires the input of electrical energy in the range of 8000 - 13 500 kilowatt-hours per tonne (kW-h/t). The group includes silicon metal, ferrosilicon and silicon carbide. Substantial quantities nf coke are used in the manufacture of these products.

With the exception of aluminum metal, there is no production of Group I materials in British Columbia. The Alcan aluminum refining plant, near Kitimat, imports its raw materials. A large proportion of the silica and magnesite mined in the province is exported with little or no upgrading.

Silicon metal production is divided into two major categories: chemical and metallurgical. The purer chemical-grade silicon is a starting material for production of silicon tetrachloride (tetrachlorosilane), silanes, silicones, semiconductor-grade silicon, high-purity fused silica and other products (Coope, 1989). The world consumption of chemical-grade silicon is expected to grow rapidly because of the variety of uses of its derivatives, and the relative immaturity of their markets. The metallurgical-grade silicon market is more competitive because of low-cost exports from Argentina, Brazil, China and other countries. Demand for silicon carbide in metallurgical applications (*e.g.*, as a deoxidant in steel making) is forecast to increase in Southeast Asia as steel production expands in that region. Applications of silicon carbide in refractories (*e.g.*, silicon-bonded silica-carbide shapes), as an abrasive and in advanced ceramics are relatively stable. Besides the steel industry, silicon carbide refractories are used in electrical generating plants, waste incinerators and other applications (Skillen, 1993).

World consumption of silicon carbide is expected to grow slightly in the next few years. However, the location of production facilities will change in response to rising energy costs and as more stringent environmental controls are applied. New plants are designed with environmental restrictions in mind and are more energy efficient. Plants that use obsolete technology must address new environmental requirements through costly retrofitting, or risk closure.

Ferro-silicon supply currently outstrips demand. The opportunity for new developments in ferrosilicon production, as in the case of silicon, lies in relocating to areas of low energy costs with available raw materials. The rationalization of production capacity, as described by Robinson (1993) will continue. However, these unfavorable market conditions may not deter the entry of plants with new technology into the marketplace.

The magnesium and aluminum markets are very competitive (Krammer, 1993; Ridgway, 1993; Humprey 1993). Worldwide rationalization in the aluminum industry is taking place and numerous new projects are in various stages of planning or construction in anticipation of market improvements (Chevalier, 1993). The Guangxi Pingguo Aluminum Corporation's project, which may indicate the importance of future Chinese involvement, is expected to have an annual capacity of 300 000 tonnes of alumina and 100 000 tonnes of aluminum metal in its first stage (Mining Journal, 1993b). The outcome of aluminum negotiations concerning aluminum production cutbacks that took place in Brussells, and the degree to which signatory countries will adhere to the agreement, will reflect on the aluminum market in the near future. The automotive market for aluminum is expected to expand over the next ten years. Currently there are about 86 kilograms of aluminum per car and there will be about 258 kilograms in the next decade, according to General Motors (Platt's Metals Week, 1994b).

Production cutbacks and trade disputes were widespread in the magnesium industry in 1992 and 1993 (Ridgway, 1993), but research and development, new expansions and construction of new plants is underway. Noteworthy developments include the construction of a magnesium metal and alloy plant in Israel by Dead Sea Works Limited. In Quebec, further research was carried out on the Magnola technology that is claimed to be the lowest operating cost primary magnesium producing process using asbestos tailings as feed. Magmetal is focusing on magnesium metal production from a large magnesite deposit located at Kunwarara, central Queensland. (Platt's Metals Week, 1994c).

Group II: Small-tonnage Fused Products (fused silica, alumina and magnesia)

This group consists of silica and magnesite-based products which involve production capacities of 5000 to 25 000 tonnes annually, with an average of 10 000 to 15 000 tonnes. Their production requires a less intensive input of electrical energy, in general less than 5000 kW-h/t. Examples of this group include refractory-grade fused silica and fused magnesia. Fused magnesia is currently produced in Alberta from magnesite mined in British Columbia by Baymag Mines Co. Limited. British Columbia has the raw materials used in refractories; materials for non-refractory applications might have to be imported. Various grades of fused alumina belong to Group II, however, raw materials for fused alumina production would have to be imported into British Columbia.

Word demand for high-purity, non-refractory fused silica, estimated at 20 000 tonnes (Roskill, 1992), is forecast to increase fastest in semi-conductor processing and in fibre optics. No published production statistics are available for the refractory grade fused silica, but demand is expected to exceed that of non-refractory fused silica. Fused silica hasa wide variety of uses from refractories to crucibles, optical elements, fibre optics, electronics, tubing in infrared radiant heating systems and in chemical applications. Synthetic silica or silicon tetrachlorite (derived from chemical grade silicon) are the main starting materials in production of high-quality optics and optical wave guides for fibre optic systems.

The magnesia market is large, but very competitive (Coope, 1993). In British Columbia, excellent quality magnesite is mined near Mount Brussilof by Baymag Mines Co. Limited (*see* Table 1) and is shipped to Alberta where it is processed into calcined and fused magnesia. The latter is produced exclusively for the refractory market. Baymag's parent company, Refratechnik GmbH has other plants at Göttingen and Kraichtal-Gochsheim in Germany and Gornal in Spain. Refratechnik produces a range of products including magnesia spinel bricks, fired magnesia bricks, magnesia graphite bricks, fireclay and high-alumina bricks as well as whole range of so-called unshaped refractories.

Group III: Limited Tonnage Products (Electrofused Products and Zirconium Metal)

This group includes a variety of products made from magnesite, alumina, chrome, zirconia and zirconium metal that are produced in limited tonnages of 2000 to 5000 tpa. Production requires a highly variable input of electrical energy ranging from 2500 to 62 000 kW-h/t. The group includes fused alumina-magnesia (spinel), fused alumina-zirconia-silica (AZS), synthetic mullite, fused zirconia, fused chrome-magnesia, and other products. These high-priced products are used in modern, high-performance ceramics and refractory products.

Fused alumina-magnesia spinel, fused zirconia, AZS fused shapes, AZS bricks and synthetic mullite are good examples of niche products belonging to this group that represent recently established growth markets. Products related mainly to steel manufacture are forecast to show strongest growth in China and, to a lesser extent, other Southeast Asian countries and worldwide. Products used in the aluminum, glass and speciality cement industries are expected to show more uniform growth world wide. Alumina-magnesia spinel is the main substitute for mag-chrome refractories in industrialized countries.

The use of mag-chrome refractories is decreasing in North America, Europe and Japan because of environmental concerns with chrome. Some of the developing countries, where environmental problems are less sensitive, are expected to continue using mag-chrome products for some time to come. This is supported by a recent transfer of mag-chrome brick technology from Refratechnik GmbH of Germany to Associated Cement Co. of Bombay, India (Industrial Minerals, 1994a).

Group IV: Other Products

This group contains specialty products that do not fit into groups I through III. Polysilicon, single silicon crystals, synthetic quartz, sodium silicate, precipitated silica, mineral wool, fibre glass and synthetic diamond are well known examples. Polysilicon and single silicon crystals are both extremely energy-intensive products, consuming approximately 160 kW-h/kg and 110 kW-h/kg respectively. The impact of power costs on competitiveness in the manufacturing of these materials is extreme even if an annual capacity of a typical plant is less than 1000 tonnes/year.

For example, there is an opportunity for a sodium silicate producing plant because there are none in Canada, west of Toronto (Boucher, 1993). The main sodium silicate uses are in detergents, synthetic zeolite production, pulp and paper manufacture, newsprint indirstries and precipitated silica manufacturing. Sodium silicate is available in liquid or briquette form (sodium silicate glass) which is easy to transport and can be liquified near industrial centres. Several pulp mills in the Province are large consumers of sodium silicate. It's manufacture is discussed by Coope (1989).

Other members of this group include some advanced ceramics and synthetic minerals that are produced at a "nearly laboratory scale" or have restricted markets. Boron carbide, boron nitride, silicon nitride, titanium diborite, zirconium diborite and sialons are a few examples described by

Haries-Rees (1993). Specialty fibres and whiskers are described by Bray (1993) and by Ault and Yeckley (1993). Some of the moderately energy intensive products such as rock wool, glass, fibre glass, sodium silicate and precipitated silica are also included in this group.

Precipitated silica is commonly produced by reaction of sodium silicate with sulphuric acid. It has applications in the rubber and paint industries, and also in manufacturing thickening and polishing agents.

The only synthetic quartz plant in Canada is located near Trois Rivières, Québec, and has a 40-tonne annual capacity (Boucher, 1993). Total consumption of cultured quartz was estimated at 1500 to 2000 tonnes worldwide. According to Roskill (1992) it is expected to grow at 5% per year. The price of cultured quartz is in the $US25-30 per kilogram range as grown and over $US100 per kilogram in lumbered form. In the past, one deposit in British Columbia supplied raw material for synthetic quartz production (Foye, 1987). Demand for polysilicon and single silicon crystals is expected to continue to grow and new production facilities will doubtless be located in areas of low electricity cost, such as British Columbia.

Fibre glass is used mainly as insulation or a reinforcing material. Stringent insulation standards that are being established in British Columbia and elsewhere are expanding the current market. The reinforcing glass fibre market is closely linked to the automotive industry (Russell, 1991). If the recent gradual opening of the Japanese market to glass imports is not disrupted, Japan may represent a new, previously inaccessible market.

SUMMARY OF OPPORTUNITIES

Refractory Minerals

British Columbia has documented deposits or occurrences of magnesite, silica, olivine, kyanite, andalusite, shale, diatomite, pyrophyllite, graphite, dolomite and brucite. Magnesite and silica are mined in the province and distributed to local and export markets. Furthermore, large undeveloped deposits of these two minerals are known in the province.

Value-added Products

A large variety of energy-intensive, value-added materials are marketed world-wide. Considering world-scale markets, technology and regional energy costs, British Columbia is a favorable location for future plants. Energy-intensive, value-added materials include light metals, such as magnesium and aluminum, metallurgical and chemical-grade silicon, ferrosilicon and silicon carbide, sintered or electrofused refractories, synthetic abrasives, reinforcing or insulating fibres, traditional or advanced ceramics, glass and intermediate products used in the electronic and chemical industries. Niche markets within the fields of electrofused minerals, advanced ceramics and electronic products should not be overlooked.

Large-tonnage Products

The potential to produce some high-tonnage products such as metallurgical and chemical-grade silicon, ferrosilicon and silicon carbide has attracted ongoing interest from international companies. The aluminum, magnesium, silicon, ferrosilicon and silicon carbide industries are going through a period of rationalization. All producers are improving their competitiveness by cutting production costs. At the same time, new projects taking advantage of recent technological advances are under construction or are in various planning stages.

Niche Market Products

The flexibility of many newly built electrofusing plants increases sales by combining several small niche markets of similar materials and provides insurance against closure due to a abrupt downturn in demand for a particular product. British Columbia is an attractive site for such a plant. Specific niche markets within the field of advanced ceramics and electronic products are also growing but from much smaller base. Industrial-scale sinterable silicon carbide, synthetic whiskers and fibres, polysilicon and single silicon crystal projects are under construction or in the planning stages.

FURTHER INFORMATION

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APPENDIX I - ENERGY AND INFRASTRUCTURE

ENERGY

The processing of industrial minerals can be energy intensive and a variety of energy sources are used (Duncan and McCracken, 1981; O'Driscoll, 1989). This is particularly the case in the production of high-performance refractory, electrofused and synthetic products. This section gives a background to energy resources of British Columbia. The Energy Supply and Requirements Forecast (1993-2015) published by the Ministry of Energy, Mines and Petroleum Resources (1993) describes the anticipated energy needs of the province in detail. British Columbia is expected to remain close to energy supply-demand balance, as rising oil imports are offset by growth in natural gas exports. The text which follows consists largely of extracts from this forecast.

Electricity

British Columbia is fortunate to have an abundance of hydro-electric capacity and good potential for further development. It is a net exporter of electricity. The British Columbia Hydro and Power Authority, a Crown corporation, produces approximately 80% of the electricity consumed in the province and serves over 1.3 million customers (Figure 7). Another major utility, West Kootenay Power, serves more than 63 000 customers in the southern Interior. The remainder of British Columbia's power is produced by industry, mainly pulp and paper mills, Alcan's hydro-electric plant near Kitimat and Cominco's facilities in the West Kootenays.

In November 1992, the government issued Special Directive No. 8 to the B.C. Utilities Commission requiring that B.C. Hydro electricity rates be set at a level sufficient for the company to earn a rate of return comparable to investor-owned utilities. In order to avoid sharp rate increases the directive also capped increases at two percentage points above the annual inflation rate. BC Hydro's rates are competitive if compared to the rest of the industrialized nations. They are well under half of the average cost of electricial power in the United States and Japan (Figure 8) and less than one-third of costs in Great Britain and Germany.

Because electricity is the most important energy source in the production of electrofused minerals and other materials such as magnesium and aluminum, B.C. Hydro's industrial electricity rates and other pertinent information are described in the Appendix II. Privately generated electrical energy, such as Alcan's and Cominco's power supplies, have negotiable price rates.

Natural gas

Natural gas is produced in northeastern British Columbia, a part of the western Canadian sedimentary basin, and is brought to market by Westcoast Energy Inc. transmission pipelines. Three utilities, B.C. Gas Utility Ltd., Pacific Northern Gas Ltd. and Centra Gas British Columbia Inc. operate the province's main gas distribution systems. B.C. Gas is the largest distributor, serving more than 600 000 customers in the Lower Mainland and Interior. The locations of major pipelines are shown on Figure 9.

Oil

Over the forecast period, oil is expected to lose market share to both natural gas and electricity, falling from 37% to 29% of provincial energy requirements. More than 80% of British Columbia's oil supply is imported, primarily from Alberta. With declining provincial production, that import share will probably rise to over 90% by 2015. Pipelines and barges bring both crude oil and refined petroleum products to Vancouver area refineries and terminals for further processing or distribution. Trans-Mountain Pipe Line Company Ltd. operates the main transmission line carrying Alberta crude and refined petroleum products. Westcoast Petroleum Ltd. owns a smaller pipeline from northeast British Columbia to Kamloops. In 1993, the three refineries in the province produced about 16 million barrels of refined product.

Prices for crude oil were deregulated under the March, 1985, Western Accord between Canada and the four western producing provinces. Since the accord was signed, Canadian crude prices have closely tracked developments in world oil markets.

Other fuels

Other fuels consumed in British Columbia include coal and coke, wood and wood-wastes (biomass), spent pulping liquors and waste gases. Total requirements for these fuels are projected to grow only marginally, at an average rate of 0.5% per year over the forecast period.

INFRASTRUCTURE

British Columbia has a modern, efficient infrastructure in the southern third of the province where most of the population and industry are located. Details of the infrastructure and the investment climate are given in a publication entitled "Investment Climate - British Columbia", published by the British Columbia Investment Office (1993).

Roads and railways

A well maintained, all-weather highway system (Figure 1.2) permits efficient long-distance trucking within the province and provides connections with interprovincial and U.S. interstate routes. National and provincial rail lines link British Columbia's industrial centres to terminal points across Canada. Five U.S. rail lines serve the province. Freight transfer is handled efficiently through computerized traffic management and integrated rail-truck terminals at main rail points.

Ports

British Columbia has an efficient system of ports, all ice-free and offers excellent tidewater sites for heavy industry (Figure 1.2). Vancouver is Canada's largest port and the second largest on the west coast of the continent in terms of tonnage handled. The port has facilities for bulk cargo, containers and ocean cruise ships. Prince Rupert is the province's second major deep-water port, mainly handling bulk commodities. There are 22 subsidiary deep-water ports serving coastal communities and resource processing industries.

Air

Vancouver International Airport (Figure 1.2) is served by 25 international airlines providing passenger and freight service to 40 countries throughout North and South America, Asia, the South Pacific and Europe. There is also regularly scheduled intercity service throughout the province. Vancouver is an important trans-shipment point between Asia and Europe for marine and air cargo and a key distribution centre for air freight to be trucked to North American markets.

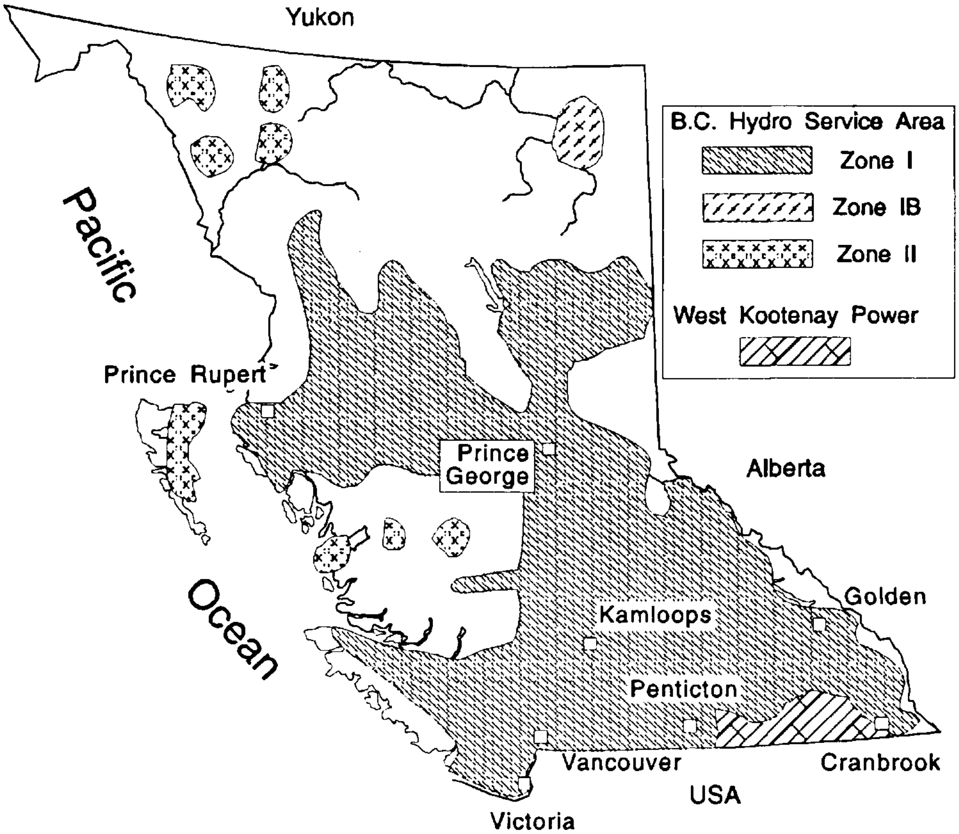

Figure 7. Electricity; BC Hydro and West Kootenay Power service areas.

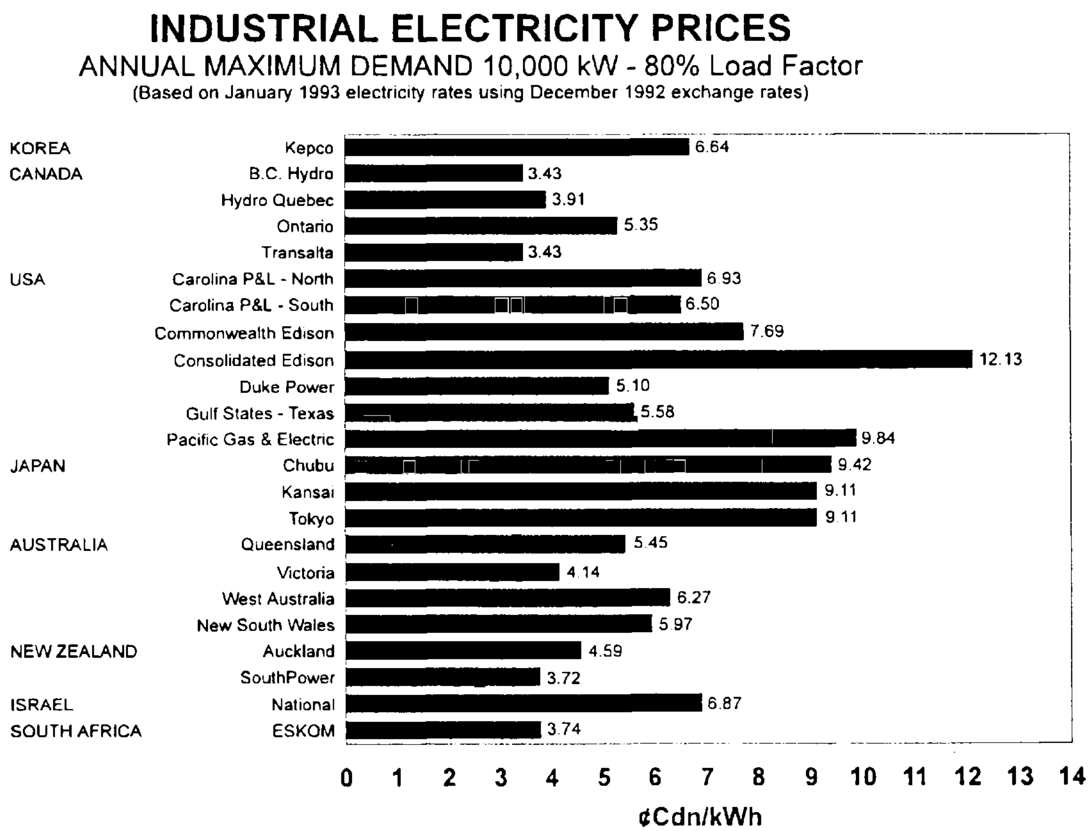

Figure 8. Electricity prices in various industrialized countries. In several jurisdictions electricity contracts are negotiable. Source: Electric Association, Economic Affairs, London, UK.

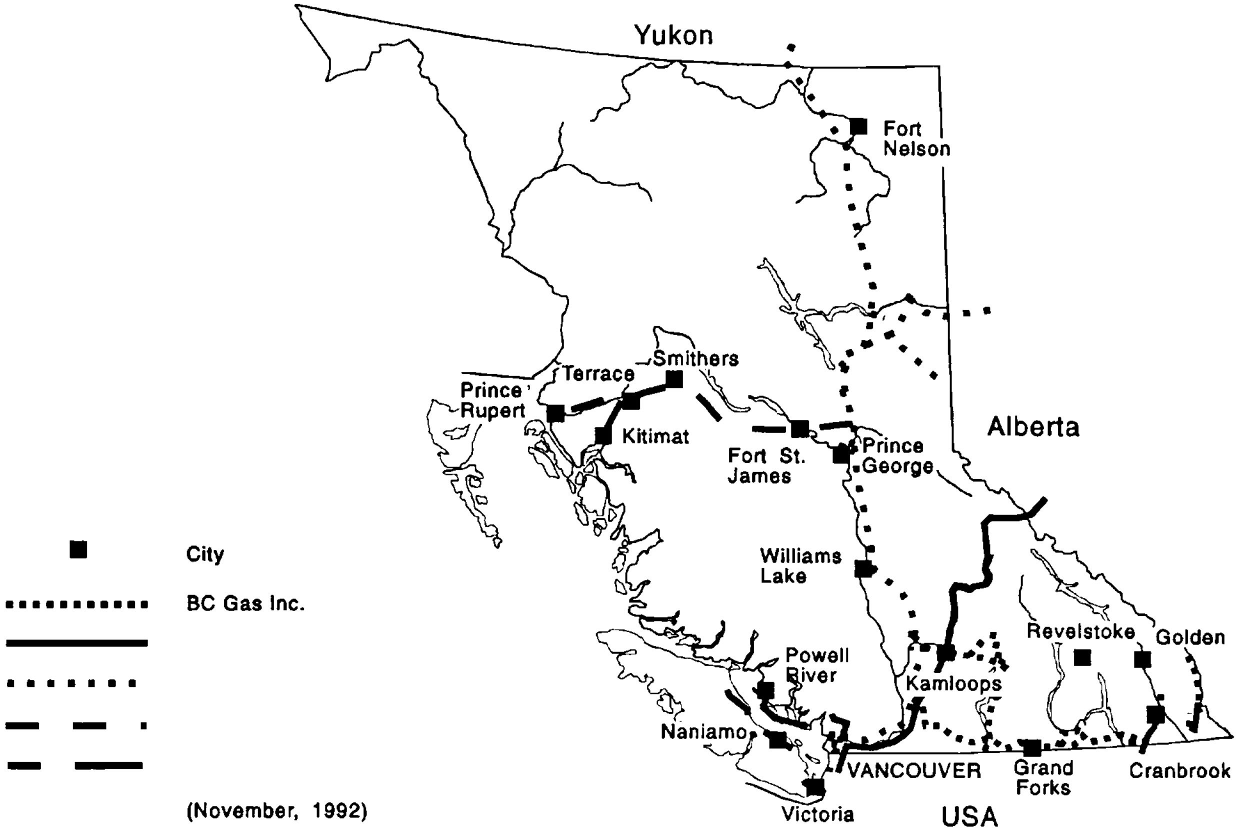

Figure 9. Major pipeline corridors.

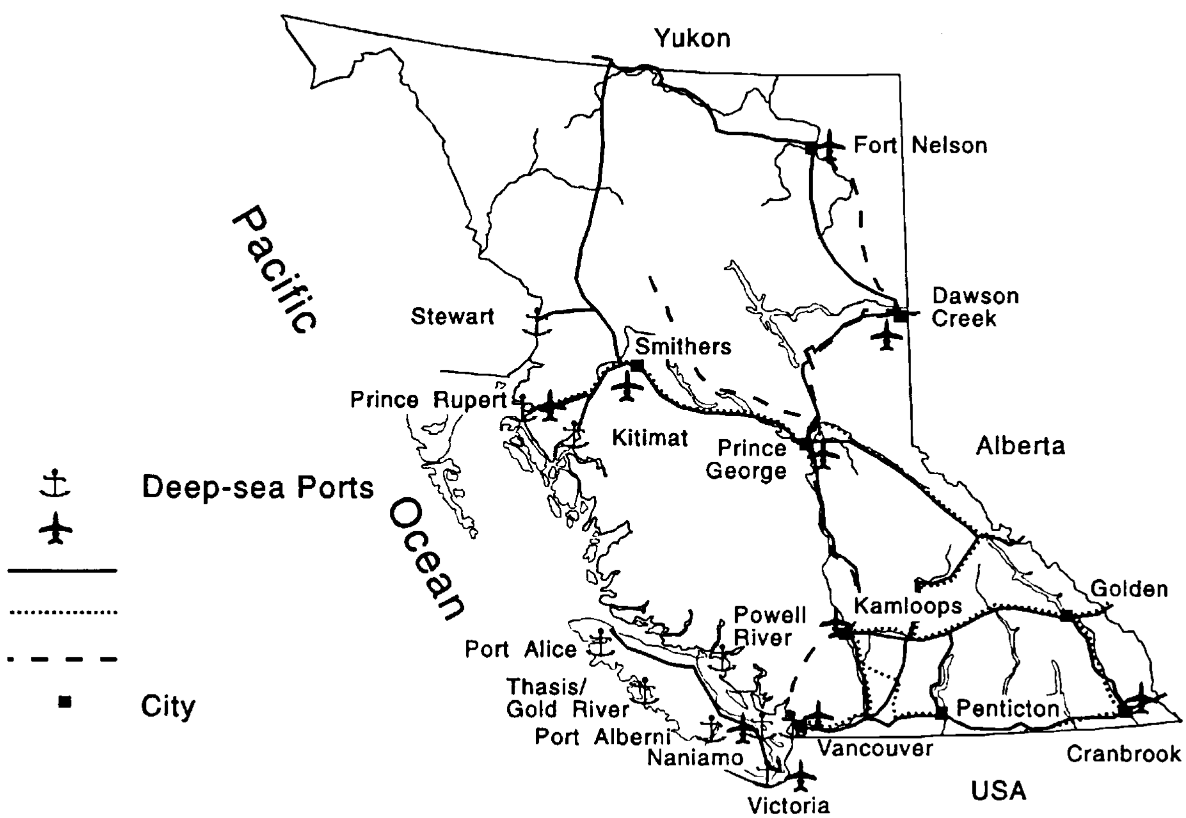

Figure 10. Selected deep-sea ports, railways, highways and airports.

APPENDIX II - ELECTRICITY SUPPLY

B.C. HYDRO

British Columbia Hydro and Power Authority is a provincial Crown corporation. It is the third largest electric utility in Canada and serves more than 1.3 million customers in an area containing over 92% of British Columbia's population. Between 43 000 and 50 000 gigawatt-hours of electricity are generated annually, depending upon prevailing water levels, mainly by hydro-electric generating stations. Electricity is delivered to customers through an integrated system of over 68 000 kilometres of transmission and distribution lines.

ELECTRICITY SUPPLY

Customers with electricity demands of about 5000 kV.A and higher are generally supplied with electricity at transmission voltage - 69 000 to 287 000 volts.

BC Hydro's Rate Schedule 1821 applies to transmission customers ($4.411/kV-A/month and 2.599 ¢/kW-h at Feb 1, 1995) in Canadian funds.

Example - Rate Calculations:

Loads (kV-A)	Monthly Demand Charge	Monthly Energy Charge	Total Monthly Bill	¢/kW-h
10 000	$ 44 110	$142 217	$186 327	3.41
50 000	$220 550	$711 085	$931 635	3.41

The above calculations assume an 80% load factor and 95% power factor. The charges do not include a 7% Social Services Tax.

Electric Facilities

The transmission system supplying industrial customers can be modified to accommodate a new customer. The modification cost is dependent on location and size and characteristics of customer's electrical equipment. BC Hydro works closely with customers to meet system technical requirements and yet keep costs for both B.C. Hydro and the customer to a minimum. The locations of existing major B.C. Hydro facilities are shown in Figure 2.1.

Negotiated Electricity Supply

In addition to Schedule 1821, B.C. Hydro is developing proposals, such as time of use rates, that will provide opportunities for lower cost electricity in exchange for supply flexibility.

As well, a marketing initiative aimed at serving short-term electricity markets under electricity supply contracts is being considered.

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY
ELECTRIC TARIFF

Twentieth Revision of Page C-54: Effective: 1 April 1993

SCHEDULE 1821

TRANSMISSION SERVICE (5000 kV-A and over)

Availability: For all purposes. Supply is at 60 000 volts or higher.

Rate: *Demand Charge:* \$4.411 per kV-A of billing demand per billing period

plus

Energy Charge: All kW.h per billing period at 2.599¢ per kW-h.

In Canadian funds.

Billing Demand: The demand for billing purposes shall be:

1. 5000 kV-A; or
2. the highest kV-A demand in the billing period; or
3. 75% of the highest billing demand for the customer's plant in the immediately preceding period of November to February, both months included; or
4. 50% of the contract demand stated in the electricity supply agreement for the customer's plant,

whichever is the highest value, provided that for new customers the billing demand for the initial two billing periods shall be the average of the daily highest kV-A demands for the customer's plant.

Monthly

Minimum Charge: \$4.411 per kV-A of billing demand.

Taxes: The rates and monthly minimum charge contained herein are exclusive of the Goods & Services Tax, and Social Services Tax.