Volume 5-Chapter 14

CHARACTERISTICS OF THE MINERAL INDUSTRY: COPPER, NICKEL, AND COBALT

Minnesota Environmental Quality Board
Regional Copper-Nickel Study
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TABLE OF CONTENTS

Volume 5-Chapter 14 CHARACTERISTICS OF THE MINERAL INDUSTRY: COPPER, NICKEL, AND COBALT

REGIONAL COPPER-NICKEL STUDY REPORT OUTLINE

A NOTE ABOUT UNITS

This report, which in total covers some 36 chapters in 5 volumes, is both international and interdisciplinary in scope. As a result, the problem of an appropriate and consistent choice of units of measure for use throughout the entire report proved insurmountable. Instead, most sections use the system of units judged most common in the science or profession under discussion. However, interdisciplinary tie-ins complicated this simple objective, and resulted in the use of a mix of units in many sections. A few specific comments will hopefully aid the reader in coping with the resulting melange (which is a reflection of the international multiplicity of measurement systems):

1) Where reasonable, an effort has been made to use the metric system (meters, kilograms, kilowatt-hours, etc.) of units which is widely used in the physical and biological sciences, and is slowly becoming accepted in the United States.

2) In several areas, notably engineering discussions, the use of many English units (feet, pounds, BTU's, etc.) is retained in the belief that this will better serve most readers.

3) Notable among the units used to promote the metric system is the metric ton, which consists of 2205 pounds and is abbreviated as mt. The metric ton (1000 kilograms) is roughly 10% larger (10.25%) than the common or short ton (st) of 2000 pounds. The metric ton is quite comparable to the long ton (2240 pounds) commonly used in the iron ore industry. (Strictly speaking, pounds and kilograms are totally different animals, but since this report is not concerned with mining in outer space away from the earth's surface, the distinction is purely academic and of no practical importance here).

4) The hectare is a unit of area in the metric system which will be encountered throughout this report. It represents the area of a square, 100 meters on a side (10000 m^2), and is roughly equivalent to 2½ acres (actually 2.4710 acres). Thus, one square mile, which consists of 640 acres, contains some 259 hectares.

The attached table includes conversion factors for some common units used in this report. Hopefully, with these aids and a bit of patience, the reader will succeed in mastering the transitions between measurement systems that a full reading of this report requires. Be comforted by the fact that measurements of time are the same in all systems, and that all economic units are expressed in terms of United States dollars, eliminating the need to convert from British Pounds, Rands, Yen, Kawachas, Rubles, and so forth!

<u>Conversions for Common Metric Units Used in the Copper-Nickel Reports</u>

1 meter	=	3.28 feet = 1.094 yards
1 centimeter	=	0.3937 inches
1 kilometer	=	0.621 miles
1 hectare	=	10,000 sq. meters = 2.471 acres
1 sq. meter	=	10.764 sq. feet = 1.196 sq. yards
1 sq. kilometer	=	100 hectares = 0.386 sq. miles
1 gram	=	0.037 oz. (avoir.) = 0.0322 Troy oz.
1 kilogram	=	2.205 pounds
1 metric ton	=	1000 kilograms = 0.984 long tons = 1.1025 short tons
1 m^3	=	1.308 yd^3 = 35.315 ft^3
1 liter	=	0.264 U.S. gallons
1 liter/minute	=	0.264 U.S. gallons/minute = 0.00117 acre-feet/day
1 kilometer/hour	=	0.621 miles/hour
degrees Celsius	=	(5/9)(degrees Fahrenheit -32)

Volume 5-Chapter 14 CHARACTERISTICS OF THE MINERAL INDUSTRY: COPPER, NICKEL, AND COBALT

14.1 INTRODUCTION AND SUMMARY OF FINDINGS

Minnesota's copper-nickel resource development depends on many factors, among them the state's attitude toward mineral development in the Study Area, mineral development company policy, and, perhaps most importantly, market conditions for the mineral commodities which would be produced by a Minnesota operation--copper, nickel, cobalt, and other precious metals. The attitude of the state is determined by its legislators, administration, and agency representatives. Through their actions, the behavior of mineral development companies can be influenced to a degree. The state, however, can do little to influence the markets in which the state's mineral resources will be traded. Therefore, this paper presents the potential metal commodity background against which state actions must take place.

A mineral development company must make a return from the large capital investment committed to successfully mine and market the state's mineral resource. An operation's profitability is first and foremost dependent on the market conditions in which it operates--supply, demand, and commodity prices. This section examines the past, present, and forecasted market conditions for copper, nickel, and cobalt to characterize the factors which may influence the development of Minnesota's resources.

The mineral industry is basic to the economy of all developed countries and many developing countries. In the developing countries of Africa and South America, exports of copper, nickel, and cobalt provide a primary source of foreign exchange and are crucial to the maintenance of governmental expenditures. The forces which affect this industry are essentially the same as those which shape the world economy as a whole. Growth in the mineral industry is inexorably tied to growth of industrial activity and consumer spending. The demand for, supply and price of mineral commodities are elements of the industry which must be examined to set the stage upon which Minnesota's potential copper-nickel industry will act.

Copper, nickel, and cobalt supplies in the U.S. have significantly different characteristics. The U.S. is the world's leading primary (from mines) producer of copper with about 20 percent of total world primary production. Primary production of nickel in the U.S. is extremely small, with a single mine in Oregon the only currently producing operation. At present there is no primary production of cobalt in the U.S. Worldwide, the copper and nickel markets are suffering from large oversupplies of the two metals, though these are slowly being reduced. Because cobalt is predominantly found in association with copper and nickel, its production is related to the production of its host metals. However, recent demand for cobalt has been strong, resulting in a relative shortage of cobalt in the U.S. and worldwide.

Minnesota's copper-nickel resource represents approximately 6 percent of United States copper resources and little more than 1 percent of world copper resources (including seabed resources). Minnesota's nickel resource is much more significant, accounting for approximately 60 percent of United States resources but less than 1 percent of the world nickel resource (including seabed resources). The estimated cobalt content at Minnesota's copper-nickel resource represents 75 percent of identified United States cobalt resource and approximately 13 percent of the world resource.

The demand for copper, nickel, and cobalt is closely tied to industrial and consumer activity. However, because of the effects of substitution and reduced intensity of use, the demand for copper and nickel in the U.S. has remained relatively stable over the recent past. The demand for cobalt moves independently of the forces which effect copper and nickel and has shown some increase in the past ten years. It is projected that by the late 1980's the demand for U.S. produced copper will exceed the available copper capacity of the U.S., given present trends in capacity expansion and U.S.B.M. demand projections.

A single Minnesota copper-nickel operation, as described in Volume 2, could contribute about one-third the necessary capacity expansion required to meet projected copper demand for the late 1980s.

The interaction of demand and supply determines the price at which mineral commodities are traded. The present oversupply of copper and nickel has resulted in a slump of their respective prices, while the price of cobalt has been on the rise due to its strong demand relative to supply. The low copper and nickel prices experienced in the past few years due to an inbalance of supply and demand has resulted in an accumulation of metal stockpiles within the industry. Over this period of declining price, in an effort to reduce its stockpiles, the industry has attempted to reduce its surplus capacity by closing down many existing operations and postponing plans for capacity expansion.

Commodities Research Unit, Inc. (an international minerals consulting firm) has projected copper prices to most likely be \$.91 per pound (in \$1977) by 1985 and the nickel price (in \$1977) to fall to \$1.99 per pound by 1985. Other sources indicate a much higher copper price by the late 1980s.

The mineral industry is dominated by large, fully-integrated corporations, which often have interests in several minerals and other natural resources. Within the last ten years, the oil companies of the U.S. have made a move into the copper industry, acquiring as much as 40 percent of U.S. capacity. A major question in the future of domestic copper, nickel, and cobalt supply is the likelihood of deep-sea mining of manganese nodules deposited on the ocean floor which are high in copper, nickel, and cobalt content. The copper and nickel industries, though presently in a slump, remain optimistic for the period beginning in the mid-1980s when present oversupplies of mineral stocks are expected to be reduced and supply and demand should again be in balance. Historically the copper industry is characterized as a relatively instable industry which is subject to periodic cycles of excess capacity and low prices followed by periods of inadequate supplies and higher prices.

14.2 COPPER INDUSTRY STRUCTURE

The United States is the leading copper producer in the world (see Table 1) accounting for about 20 percent of world production; ahead of Chile, the USSR, Canada, Zambia, and Zaire. Within the country, Arizona is by far the dominant copper-producing state (see Table 2), with the remainder provided by Utah, New Mexico, Montana, Nevada, Michigan, Missouri, and Tennessee.

<u>Tables 1 and 2</u>

Table 1. World copper metal production capacities, 1975, 1976, and 1980 (thousand metric tonnes).

	1975	1976	1980
North America:			
United States:			
Mine	1,814	1,814	1,950
Smelter	1,814	1,814	1,905
Refinery	2,594	2,630	2,630
Other North America:			
Mine	989	1,016	1,261
Smelter	744	744	1,043
Refinery	698	698	939
South America:			
Mine	1,107	1,252	1,615
Smelter	1,034	1,034	1,306
Refinery	1,025	1,025	1,306
Europe:[1]			
Mine	254	254	272
Smelter	717	717	753
Refinery	1,651	1,651	1,714
Africa:			
Mine	1,651	1,651	1,814
Smelter[2]	1,696	1,696	1,787
Refinery	1,152	1,152	1,651
Asia:[1]			
Mine	599	535	862
Smelter	1,388	1,388	1,814
Refinery	1,370	1,370	1,596
Oceania:			
Mine	435	435	454
Smelter	227	227	227
Refinery	209	209	209
Centrally Planned Economies:			
Mine	1,542[3]	1,633[3]	2,268
Smelter	1,678[3]	1,769[3]	1,950
Refinery	1,678[3]	1,769[3]	1,950
World Total:			
Mine	8,391	8,590	10,496
Smelter	9,298	9,389	10,785
Refinery	10,377	10,504	11,995

SOURCE: USBM 1977.

[1]Market economy countries.
[2]Includes electrowinning capacity in Zaire and Zambia.
[3]Estimated.

Table 2. 1977 U.S. copper mine production (metric tonnes of metal).

STATE	PRODUCTION	PERCENT SHARE
Arizona	845,355	61.4
Michigan	39,365	2.9
Missouri	11,065	.8
Montana	80,725	5.9
Nevada	60,635	4.4
New Mexico	151,565	11.0
Utah	175,690	12.8
Other States	12,500	.8
TOTAL	1,376,900	100

SOURCE: USBM 1978.

Minnesota's resource, estimated to contain 26,340,000 metric tonnes of copper, is approximately one-quarter the size of total U.S. reserves and one-twentieth the size of world reserves.

If Minnesota's copper-nickel resource is developed with annual production of 254,000 metric tonnes of copper (the equivalent of three hypothetical mine, mill, smelter-refinery complexes at full production in the Study Area) the state would have approximately 10 percent of 1977 U.S. refinery capacity (CRU 1977) and 19 percent of 1977 U.S. refinery production (USBM 1978). This amount of production would make Minnesota the second leading copper-producing state in the U.S., based on 1977 production levels, with 15.6 percent of total U.S. mine production and would represent 13 percent of USBM forecasted 1985 primary copper demand.

Copper production requires three stages: mining, smelting, and refining. These stages can operate independently but most often are part of an integrated corporate operation.

World copper mine, smelter, and refinery capacities are expected by 1980 to expand 22, 15, and 14 percent, respectively, from 1976 levels. South America and Asia are projected to expand mine capacity by about 350,000 metric tonnes each by 1980. The largest share of mine growth, however, is seen to be in the Centrally Planned Economies, with 635,000 metric tonnes expansion. The largest smelter capacity expansion is expected to develop in Asia, particularly Japan, where much ore from Australia, New Guinea, and other oceanic developments is smelted. Africa leads the way in new refinery capacity as the developing countries with rich copper deposits seek to capture more of its value. Refinery products are the major commodities which are traded on the international markets. They appear in forms which are usable by particular consumers, such as brass, wire or powder mills, foundries and forging, or chemical plants. Copper may appear as refinery cathodes or cast or extended into wirebars, billets, tube billets, cakes or ingots.

Copper is commonly used in alloys such as brass and bronze, but also is used in alloy with nickel, aluminum, cadmium, and tellurium. Its largest use, due to its high degree of conductivity (see Table 13), is in the electrical and electronic industry. Many construction and machine products depend on copper because of its corrosion-resistant properties.

The five leading copper-producing companies are Kennecott, Phelps Dodge, Anaconda (Atlantic Richfield Company), Newmont, and Duval (Pennzoil). Many U.S. companies have interests in foreign copper operations, though these have been decreased in recent years due to nationalization of mineral operations in such countries as Chile, Peru, Zambia, and Zaire. Recent actions by Exxon in Chile imply a possible change in this trend.

Major oil companies have been acquiring copper interests at a growing pace. The copper industry, because of the current (1977-1978) slump in prices and stock value, are attractive takeover targets for the capital-rich oil companies. Since 1963, oil companies have purchased 6 of the 13 largest U.S. copper firms. In addition to its currently low prices, the copper industry is being eyed by the oil industry because of the similarity between the two industries. Both are vertically integrated industries involved in the extraction, refinement, and marketing of a natural resource. Oil companies now control about 40 percent of the U.S. copper industry (Minneapolis Star 1978). Atlantic Richfield bought

Anaconda, the fourth largest U.S. copper company, in 1976. Exxon Corporation is investing large amounts of money in its own mining ventures. Pennzoil owns Duval Corporation, the fifth largest copper company in the U.S. Standard Oil of California presently has a 20 percent interest and recently attempted to acquire a controlling interest in AMAX, Inc. In 1978 Superior Oil Company purchased Hecla Mining Company, one of the ten largest U.S. copper companies.

Many oil companies are developing internal mining divisions to explore for copper. Exxon, Continental, Gulf, and Standard are each gearing up for copper production.

Internationally, a potentially dominate force in the copper markets is the Intergovernmental Council of Copper Exporting Countries (CIPEC), made up of Chile, Peru, Zambia, Zaire, Indonesia, Australia, Papua New Guinea, and Mauritania. CIPEC was formed in 1967 and presently its members control 38 percent of world mine production and 72 percent of the export trade of mine and smelter products (USBM 1977). In 1974 CIPEC acted to reduce its export shipments by 15 percent; however, it is not certain whether compliance resulted, as there was no change in copper prices. Because of the significance of copper as a source of foreign exchange for these countries and because of the large variation in production costs between these countries, united actions affecting the production, trade levels and prices of copper are rare.

Although relatively ineffective as a force in copper trading to this point, CIPEC carries with it a tremendous potential through its share of world copper reserves. CIPEC reports that CIPEC members control 196 million metric tonnes or 43 percent of total world copper reserves. In addition, CIPEC countries generally control much higher-grade ore than the world average of .53 percent. Chile, for example, claims an average ore grade of 1.7 percent, declining to 1.0 percent by 2000 (Mining Journal 1978).

Table 3

Some developing countries in South America and Africa enjoy a tremendous competitive advantage over U.S. copper with respect to production cost and ore grade. The United States in 1975 and 1976 mined copper with an average grade of .6 percent and production cost of 48.5 cents per pound of finished copper. Zaire, on the other hand, mined 5.1 percent copper and had production costs of 48.5 cents per pound of copper; Chile mined 1.6 percent copper and had production costs of only 37.5 cents per pound.

An operation in Minnesota is estimated to have production costs, at full production, of 94 cents per pound of combined copper and nickel metal produced for an open pit complex and 98 cents per pound for underground mining. Allowing a nickel and precious metals credit against the cost gives a production cost of 62 cents per pound of copper for open pit and 67 cents per pound for an underground operation.

The relative production costs of foreign copper provides an incentive for U.S. consumers to import copper from these developing countries. These countries are extremely dependent on copper exports due to their demands for foreign exchange and have been impelled to sell copper at less than production costs. This would further put U.S. producers at a competitive disadvantage in the international markets for copper.

Tables 4 and 5

Table 3. World copper resources (million metric tonnes of metal).

	RESERVES[1]	OTHER[2] RESOURCES	TOTAL RESOURCES
North America:			
Minnesota	00	26	26
Other United States	84	264	375
Canada	31	109	140
Other	30	27	57
Total	145	426	593
South America:			
Chile	84	118	202
Peru	32	36	68
Other	20	63	83
Total	136	217	353
Europe: Total	6	36	43
Africa:			
Zaire	25	27	53
Zambia	29	63	93
Other	9	18	27
Total	63	108	173
Asia: Total	27	63	91
Oceania: Total	18	54	73
Centrally Planned Economies	60	172	232
Sea Nodules[3]	---	689	689
WORLD TOTAL	455	1,765	2,252

SOURCE: USBM 1977.

[1]Of the listed reserves, approximately one-third of the copper contained in the U.S. and market economy counting totals is located in underdeveloped deposits. These deposits can move between reserve and resource classifications depending on prevailing legal and economic conditions.

[2]Includes undiscovered (hypothetical and speculative) deposits.

[3]Estimate based on average of 1 percent copper per dry ton of nodules.

Table 4. Average 1976 copper ore grade mined (percent copper).

Africa		3.5
Zaire	5.1	
Zambia	2.6	
Australia		1.7
Asia		1.6
South America		1.5
Chile	1.6	
Peru	1.25	
Europe		1.5
North America		0.7
Canada	1.12	
U.S.	.6	
World		1.45

SOURCE: CRU 1977.

Table 5. Average 1975 copper net operating costs (cents per pound of primary refined copper).

U.S.	48.5
Africa	48.5
Canada	44.5
Non-Socialist World	44.5
Western Europe	39.0
Central and South America	37.5
Asia and Australia	34.0

SOURCE: CRU 1977.

Copper is traded on two organized markets, the London Metal Exchange (LME) and the New York Commodity Exchange (COMEX), and these markets help determine its price. The LME is generally considered to be most important as to its influence on prices. These markets are principally hedge and speculation oriented and do not deal exclusively in actual physical units. Domestic primary producers generally determine the price at which they sell their product but are closely tied to the price established by the exchanges. Producer prices are generally set by the major producers with others falling in line, although premiums and discounts can make selling more competitive.

In the United States, Kennecott and Asarco are commonly price leaders. Kennecott, early in 1978, changed its pricing policy so that its price for copper cathodes is set equal to the daily New York Commodities Exchange price plus a 2½ cent-a-pound premium (WSJ 1978). When enacted, this policy had the effect of raising Kennecott's price by three cents. Anaconda, a division of Atlantic Richfield Company and a leading copper producer, in July, 1978, adapted a pricing policy similar to that of Kennecott.

14.3 NICKEL INDUSTRY STRUCTURE

Nickel plays an important role in the steel and aerospace industries. As an alloy with other materials, its strength and corrosion resistance are of great value. The United States is the world's leading consumer of nickel (see Table 6), yet has very small reserves of the mineral. Only one domestic mine, at Riddle, Oregon, operated by Hanna Mining Company, is currently producing ore. This mine produced less than 4 percent of total U.S. supply in 1976. Nickel resources, though unmined at present, do exist in lateritic deposits in

California, Oregon, and Washington and in sulfide deposits in Minnesota, Montana, and Alaska.

Minnesota's copper-nickel resource would become the nation's largest nickel reserve when development becomes economically feasible. Minnesota has 8.0 million metric tonnes of nickel with an average grade of .2 percent (DNR 1977). This would dwarf the existing U.S. reserves of 181,000 metric tonnes and would be approximately one-eighth the size of world reserves estimated in 1978 (USBM 1978).

If three hypothetical copper-nickel operations are developed in Minnesota, annual production of 46,000 metric tonnes of nickel would more than double the 1975 U.S. nickel refinery production and would represent 6 percent of 1975 world nickel production (CRU 1977). This amount of production would represent approximately one half of the U.S.B.M. forecasted 1985 primary nickel production.

Table 6

Examination of world nickel resources shows that the U.S. has less than one percent of total world reserves, given the present conditions of the nickel market. The picture with regard to resources, given a change in the real price of nickel, is not much brighter. The U.S. controls only 1.3 percent of total world resources--according to the USBM.

Table 7

Table 6. 1976 nickel metal consumption.

	(thousand metric tonnes)	Percent Share
U.S.A.	187.3	36
Japan	113.6	22
Eastern European Countries	108.2	21
U.K.	34.9	7
Sweden	25.1	5
Others	47.5	9
Total Non-Socialist World	516.6	

SOURCE: CRU 1977.

Table 7. World nickel resources (thousand metric tonnes of metal).

	RESERVES	OTHER RESOURCES[1]	TOTAL RESOURCES[1]
North America:			
Minnesota	000	8,000	8,000
Other United States	181	5,515	5,696
Canada	8,707	10,522	19,229
Total	8,888	24,037	32,925
Africa	2,086	6,077	8,163
Central America and Caribbean Islands:			
Cuba	3,084	12,880	15,964
Dominican Republic	998	91	1,088
Guatemala	272	816	1,088
Puerto Rico	---	816	816
Total	4,354	14,603	18,956
Europe: U.S.S.R.	7,347	11,973	19,320
Oceania:			
Australia	5,079	2,902	7,982
Indonesia	7,075	5,986	13,061
New Caledonia	13,605	28,390	41,995
Philippines	4,898	5,261	10,159
Total	30,657	42,539	73,197
South America:			
Brazil	181	2,993	2,175
Colombia	816	544	1,361
Venezuela	---	635	635
Total	997	4,172	5,171
Sea Nodules		895,700[2]	
World Total (rounded)	54,329	999,101	1,053,432

SOURCE: USBM 1977.

[1]Derived in consultation with U.S. Geological Survey.
[2]Estimate based on average 1.3% nickel content of nodels.

The leading suppliers of U.S. nickel are Canada, New Caledonia, Norway, the Dominican Republic, and Australia. Canada is the leading nickel producer in the world (producing nearly one-third the world's nickel), dominating the industry with the International Nickel Company (INCO) and Falconbridge Nickel Mines Ltd.

As with the copper industry, the production of nickel requires mining, smelting, and refining stages to produce a marketable product. AMAX, Inc. owns a nickel-copper refinery in Louisiana which began production in 1974 based on a nickel-copper matte imported from Africa, producing 18,140 metric tonnes of nickel in 1976 (USBM 1977). Many companies such as AMAX operate single stages of the production process, but the dominant companies such as INCO and Falconbridge are vertically integrated and operate mines, smelters, and refineries and fabricating facilities all over the world.

Nickel is commonly found in stainless steel and other alloys and "super" alloys. Nickel's corrosion resistant and strength properties lead to its use in chemical and petroleum production, fabrication of metal products, aircraft and other transportation equipment, and many consumer and production goods.

By 1980, nickel mine, smelter, and refinery capacities are expected to expand from 1976 levels by 15, 18, and 6 percent, respectively (see Table 8). According to estimates, no capacity expansion in North America can be expected in the very near future. The largest expansion of mine capacity is expected in Latin America and Asia, while Europe joins with Latin America as the site of projected smelter capacity expansion. There is very little refinery expansion expected, with Asia being responsible for most of the small projected increase in capacity. Much of the new expansion may be delayed due to low nickel prices and present surplus supplies of this metal.

Of interest are the inbalances which exist in some areas of the world with respect to mine, smelter, and refinery capacity. Latin America and Australia/Oceania are exporters of unfinished material, while Europe depends heavily on imports to fill its refinery capacity.

Table 8

The concentration of the industry by the dominant Canadian firms leads to a very tight pricing structure (CRU 1977). INCO is the price leader and other firms adjust their prices accordingly. INCO recently curtailed its policy of publishing its nickel prices because their openly published price had become the target for discounts offered by competitors.

Minnesota operations, regardless of the cost associated with it nickel production, would be compelled to price its product in line with the prevailing INCO dominated markets.

The potential of ocean mining of mineral nodules may result in nickel production by 1985. Negotiations currently ongoing in the United Nations Law of the Seas Conference revolve around two opposing methods for developing deep-sea resources. One proposal would create an international organization, termed the Enterprise, to control all sea-bed mining. This would benefit those countries which have neither the technical or financial resources to undertake such a development, as the Enterprise would carry out its role "on the behalf of mankind." A countering proposal under discussion would allow parallel development by private, state, and international organizations. This would favor the technical- and capital-rich developed countries and insure their continued domi-

Table 8. World nickel production capacities (thousand metric tonnes of metal).

	1976	1980
North America:		
Mine	380	380
Smelter	320	320
Refinery	238	238
Latin America:		
Mine	39	83
Smelter	40	83
Refinery	4	10
Europe:		
Mine	25	48
Smelter	25	48
Refinery	118	118
Africa:		
Mine	60	60
Smelter	52	52
Refinery	28	28
Asia:		
Mine	75	121
Smelter	166	212
Refinery	85	112
Australia/Oceania:		
Mine	240	250
Smelter	130	148
Refinery	38	38
World Total:		
Mine	819	942
Smelter	733	863
Refinery	511	544

SOURCE: USBM 1977.

nance of the copper, nickel, and cobalt markets. Agreement between Canada, the world's largest nickel producer, and the United States, the worlds's largest nickel consumer, stipulates that seabed production be limited to 60 percent of the increase in annual world consumption. This would reinforce the position of the leading land-based producers, allowing them to maintain present producti levels plus guaranteeing 40 percent of the increase in consumption. Develo under the "parallel" scenario it is estimated, would allow the U.S. to redu its imports of nickel by 25 percent (Mining Journal 1978). Several consor of mineral companies have joined to initiate investment in ocean mining. is part of a group called Ocean Management, Inc. (OMI) along with Germ Japanese interests. OMI is capable of producing 2 million metric ton by 1985 (Li 1977), although the continuing slump in the nickel market considerable delay in investment.

A 3 million metric tonne per year nodule operation is capable of producin nickel at $2.00 per pound, ($1977), compared to a cost of $2.73 per pound laterite nickel and $1.27 per pound for Canadian sulfides (CRU 1977).

An operation in Minnesota is estimated to have annual production costs of 94 cents per pound of total metal produced at full production for an open pit mine, mill and smelter/refinery complex and 98 cents per pound of combined copper and nickel metal produced for an underground operation. Allowing a credit for copper and precious metals gives a nickel production cost of 49 cents per pound for open pit and 77 cents per pound for underground.

14.4 COBALT INDUSTRY STRUCTURE

The United States ceased producing primary cobalt in 1971. Since then it has depended on imports, primarily from southern Africa countries for its cobalt supply. Cobalt production is concentrated in Africa with Zaire (53%), Zambia (9%), and Morrocco (6%) dominating the industry. Australia (7%) and New Caledonia (6%) complete the top five cobalt-producing countries.

Cobalt is used primarily as an alloy in heat and corrosion resistant materials, although about 25 percent of cobalt is consumed in nonmetallic compounds such as paint, ceramics, and other chemicals (USBM 1977). Its primary use is in magnetic components in the electrical and electronic industry. Cobalt is also used in aircraft and other engine parts where strength and heat and corrosion resistance are important.

Minnesota's copper-nickel resource is estimated to contain approximately 573,000 metric tonnes of cobalt. The United States presently has no classified reserves of cobalt, but Minnesota's cobalt would be about one-fifth the size of estimated world cobalt reserves. Three hypothetical mines operating in Minnesota would produce 5,500 metric tonnes of cobalt. The U.S.B.M. estimates that U.S. primary production in 2000 will be approximately 6800 metric tonnes, indicating that Minnesota could be the leading, if not only, cobalt producing state by that time. Minnesota production of 5,500 metric tonnes would represent approximately one-third the U.S. primary demand in 2000.

<u>Table 9</u>

Table 9. World cobalt resources (thousand metric tonnes of metal).

North America:			
Minnesota	---	573	573
Other U.S.	---	191	191
Canada	30	220	250
Cuba	109	940	1,049
Total	139	1,924	2,063
Europe:			
Finland	18	5	23
USSR	209	18	227
Total	227	23	250
Africa:			
Botswana	26	5	32
Morocco	13	1	14
Zaire	454	227	680
Zambia	113	234	347
Total	606	467	1,073
Oceania:			
Austrialia	49	246	295
New Caledonia	272	113	385
Phillippines	190	14	204
Total	512	373	884
World Total	1,483	2,787	4,270

Source: USBM 1977

14.5 CHARACTERISTICS OF SUPPLY, DEMAND, PRICE

14.5.1 Copper

The copper industry is extremely competitive within the United States, with many large mineral development companies continually seeking to increase their market positions. The U.S. is both the largest consumer and supplier of copper in the world. However, the trend over the recent past has been a loss of competitive supply position to foreign sources while U.S. demand has been steady and strong. Domestic sources of copper are coming into much higher favor due to the unstable and risky nature of foreign investments over the past 20 years.

Minnesota's copper resource, given the credits it would receive from nickel, cobalt, and other precious metals, can be produced at costs which make it a marginal domestic source of the metal. Further, the slump that currently has produced depressed copper prices around the world is expected to have reversed itself by the mid-1980s as current production cutbacks and investment curtailment produce supply conditions which meet the expected demand. Due to the long lead-time necessary to bring a sizable mining operation on line, the earliest Minnesota can expect to have a producing copper-nickel operation is the mid- to late-1980s.

Should the demand for copper grow faster than expected or the pressure for a domestic source of the metal increase, Minnesota can expect to be strongly urged to allow development of its mineral resources.

14.5.1.1 <u>Supply</u>--The supply of copper in the United States comes from three principle sources: sulfide copper, oxide copper, and recycled scrap. The majority of U.S. domestic reserves are in the form of sulfide copper which tend to be large, low-grade deposits. The Minnesota copper-nickel deposits are sulfides. Less important to domestic supply are the spotty, but higher-grade oxides. However, the production from this source has been increasing over the past few years. Of growing importance is the supply of copper coming from new and old scrap. New scrap is recovered directly from the manufacturing process, while old scrap is recovered from obsolete equipment. Presently, scrap accounts for about 40 percent of domestic consumption (A.D. Little 1978) and has been a relatively stable source in the past.

A large potential source of copper is the sea bed mining of nodules along the ocean floor which are high in manganese, copper, and nickel content (Table 10). Technological problems of ocean mining are rapidly being overcome so that the sole remaining problem will be political in nature.

Because nodule deposits are located throughout the oceans of the world, jurisdiction over these areas and resulting economic benefits is being debated in the forum of the United Nations, Law of the Seas Conference. Nodule mining may be a major competitor to Minnesota copper-nickel development. Sources indicate that ocean mining could occur by 1990 (CRU 1977).

If five nodule mining operations are in operation by 1985, their production would add 19 percent to the world's production of manganese, 3 percent to the copper production, 32 percent to nickel, and 86 percent to world cobalt production (USGS 1977).

However, recent reports indicate that the present slump in copper and nickel prices are causing the estimated start-up date for deep-sea mining to slip, possibly to 1990 (WSJ 1978).

Table 10

The United States is nearly self-sufficient in copper, with net imports of about 336,000 metric tonnes, or about 4 percent of total U.S. supply of copper in 1976 (USBM 1977). Copper reserves are estimated at about 84 million metric tonnes, or about 20 percent of total world reserves (USBM 1977). In 1977 United States mines produced 1,376,000 metric tonnes of copper. Average ore grade of U.S. mine production has decreased steadily, dropping from 1.50 percent copper in 1931 to 0.47 percent copper in 1975 (USBM 1976). Other sources indicate that the average ore grade mined in 1976 was a bit higher, at .6 percent copper (CRU 1977). Despite lower-yield copper deposits, mine production during the same period has increased from 480,000 metric tonnes in 1931 to 1,376,000 metric tonnes in 1977.

Tables 11 and 12

United States refineries produced 1,598,000 metric tonnes of copper in 1977. The difference between U.S. mine and refinery production is accounted for by net imports of copper ore from foreign sources for U.S. refineries and recycled metal. United States refinery output accounted for 56 percent of the total copper supply in 1975 (USBM 1977). The remainder of U.S. supply was made up of refined imports, unrefined scrap, and industrial stockpiles.

Some trends in the composition of refinery feed can be discerned. The increase in U.S. refinery output over the past 40 years has been due to an increase in domestic mine production and the recycling of scrap copper. The share of

Table 10. Sample nodule ore grades.[1]

Manganese	24.6 percent
Nickel	1.28 percent
Copper	1.16 percent
Cobalt	0.23 percent

SOURCE: World Mining 1977.

[1]Average analysis for North Pacific, siliceous ooze.

Table 11. U.S. copper supply, 1965-76 (thousand metric tonnes of metal).

	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
Components of U.S. supply (primary and old scrap):												
Refined production:												
Domestic mines	1,212	1,227	768	1,052	1,332	1,380	1,280	1,524	1,540	1,289	1,178	1,288
Old scrap	194	220	172	210	258	252	189	192	219	243	195	204
Imports of ore, blister, etc.	341	325	259	250	249	221	164	175	154	212	131	100
Sales of Government stockpile excesses	109	363	135	---	---	---	---	---	---	229	---	---
Imports of refined	124	149	300	363	119	120	149	174	182	285	133	336
Old scrap (unrefined)	271	266	266	263	264	205	215	223	222	195	140	150
Industry stocks, Jan. 1	424	452	546	460	511	491	585	532	469	414	541	420
TOTAL U.S. SUPPLY	2,675	3,000	2,447	2,599	2,732	2,668	2,581	2,820	2,787	2,866	2,318	2,497

SOURCE: USBM 1977

Table 12. Copper ore grade, annual mine production.

YEAR	AVERAGE ORE GRADE MINED	MINE PRODUCTION COPPER METAL (000 mt)
1931	1.50	479.7
1936	1.54	557.4
1941	1.15	869.1
1946	.91	552.1
1951	.90	842.0
1956	.78	1001.5
1961	.75	1056.8
1966	.67	1296.3
1971	.55	1380.7
1972	.55	1510.1
1973	.53	1558.2
1974	.49	1448.5
1975	.47	1281.9
1976	.51	1456.7
1977	.52	1376.9

SOURCE: USBM 1976, 1978.

foreign ores going to U.S. refineries has decreased quite steadily in the past 20 years.

Other components of total U.S. copper supply include refined imports (6% of total in 1975), refined and unrefined production from old scrap (14% in 1975), and stocks from the industry (23% in 1975). The present slump has resulted in a reduction of industrial stocks in 1977 and 1978 and concomitant increase in refinery stockpiles and cutbacks in mine and refinery production.

14.5.1.2 Demand--The demand for U.S. copper production comes in three forms: industrial stock, refined exports, and industrial consumption. In 1976, 18 percent of annual production was retained as industrial stock. From 1971 to 1973 the industry reduced its stock as a result of favorable copper prices. Since 1973, however, the depressed price for copper has resulted in a net annual increase in industrial stocks. This trend has slowed in 1977 and 1978 as companies have cut back on mine and refinery production in order to reduce the existing buildup of copper stocks.

Another component of total U.S. demand is that of refined exports. Exports of copper have steadily decreased over the past twelve years. In 1965 U.S. exports were 295,000 metric tonnes, or 11 percent of total U.S. supply of copper. By 1976 the U.S. was exporting only 100,000 metric tonnes of copper-4 percent of U.S. supply (USBM 1977).

By far the largest part of total U.S. demand [78% in 1976 (USBM 1977)] is that which is consumed by various segments of the U.S. economy. The use of copper by the electrical and electronics related industries is the largest end-use category and in recent years these industries have been expanding their share of total consumption. Other end-use industries include building construction, transportation, industrial machinery and equipment, and consumer and general products.

Table 13

Copper consumption is subject to substitution by other products. Copper faces competition from aluminum, plastics, steel, glass fibers, and other minerals. Because the modification of systems from the use of one product to another is slow, the changes in substitution lag behind the incentive to substitute provided by relative price, availability or technical developments. For this reason, substitution is hard to quantify and even harder to predict. The electrical industry has seen a rise in the use of aluminum and fibre optics in the transmission of energy. Substitution is also occurring rapidly in the field of heat exchangers with aluminum again replacing copper.

Due in part to substitution, the U.S. demand for copper has remained relatively stable while in the recent past GNP and other economic indicators have risen rapidly. In 1965 industrial use amounted to 1,928,000 metric tonnes (72% of total U.S. supply). By 1976 industrial use had only grown to 1,956,000 metric tonnes or 78 percent of available supply (USBM 1977).

In summary, copper demand can be characterized by a stable industrial end use, a volatile stock held within the industry but relatively stable over the long term and decreasing exports of copper. The result has been a nearly constant supply and demand over the recent past. Since 1931, however, both supply and consump-

Table 13. U.S. copper demand, 1965-76 (thousand metric tonnes of metal).

	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
Distribution of U.S. supply:												
Industry stocks, Dec. 31	452	546	460	511	491	585	532	469	414	541	642	442
Exports (refined)	295	248	144	219	181	200	171	166	171	115	156	100
Industrial demand	1,928	2,207	1,843	1,869	2,060	1,878	1,879	2,185	2,202	2,210	1,520	1,956
U.S. demand pattern:												
Electrical	1,932	1,068	1,010	949	1,082	999	1,010	1,1136	1,311	1,134	880	1,052
Construction	376	372	251	287	309	298	318	392	322	385	218	302
Machinery	277	287	189	217	230	228	220	272	229	308	187	263
Transportation	206	205	132	175	180	157	174	206	180	233	130	209
Ordinance	41	165	171	149	156	108	63	71	52	38	31	32
Other	96	110	92	93	102	94	94	109	109	111	75	98
TOTAL DEMAND	1,928	2,207	1,843	1,869	2,060	1,878	1,879	2,185	2,202	2,210	1,520	1,956
TOTAL U.S. PRIMARY DEMAND (industrial demand less old scrap)	1,463	1,721	1,405	1,397	1,558	1,426	1,476	1,770	1,761	1,771	1,185	1,602

SOURCE: USBM 1977

tion increased threefold.

Figure 1

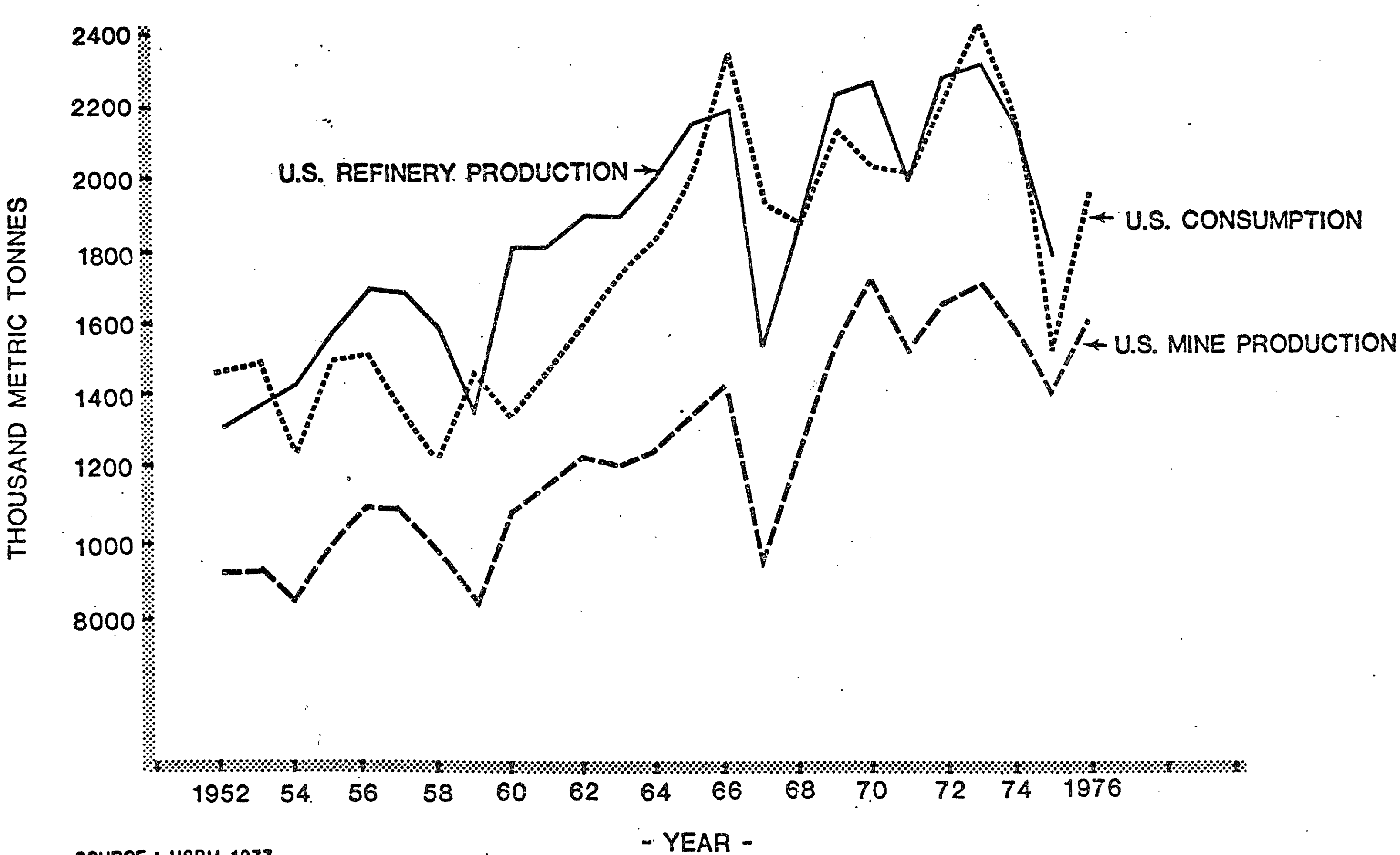
14.5.1.3 Price--Copper prices, which reflect the interaction between copper supply and copper demand, in constant dollars have been relatively stable over the past 20 years and, in fact, have been on a downward trend over the past 200 years (Douglas 1977).

Copper prices in the short-term tend to be relatively volatile. Because copper is traded on the open market as a commodity, it is subject to speculation as events which may effect supply and demand occur and as rumors of potential events circulate throughout the copper-trading community. The recent military action in Zaire demonstrates this sort of phenomenon. Rebel forces stopped activity in the copper mines of Zaire and cut off the flow of copper to the coast for shipment. The day following this action the price of copper jumped three cents per pound on the LME as news of the military action leaked out of the country. This was in response to the expectation that Zaire copper would no longer be available and worldwide copper supply would be decreased. Other events of short-term nature can also effect prices very quickly. Such things as country-wide strikes, news of copper finds or long-term contracts and possible curtailment of individual projects can all feed the short-term fires of speculation in the copper markets.

In the long run, copper prices are subject to more macroeconomic trends. Substitution of other materials for copper in many of its uses, increased recovery of copper from secondary sources, and a lower intensity-of-use as countries

FIGURE 1

COPPER PRODUCTION, CONSUMPTION



SOURCE : USBM 1977

become increasingly developed all lead to a downward trend in the price of copper. On the other hand, the scarcity of finite minerals is always pushing the value of copper upward. As well, the factors of increasing production costs and decreasing ore grade tend to push prices higher. Three elements of production cost seem destined to pull the price of copper over the long-run to higher levels: the cost of energy, labor, and pollution control. Each of these have increased dramatically in the recent past and give every indication of continuing to rise.

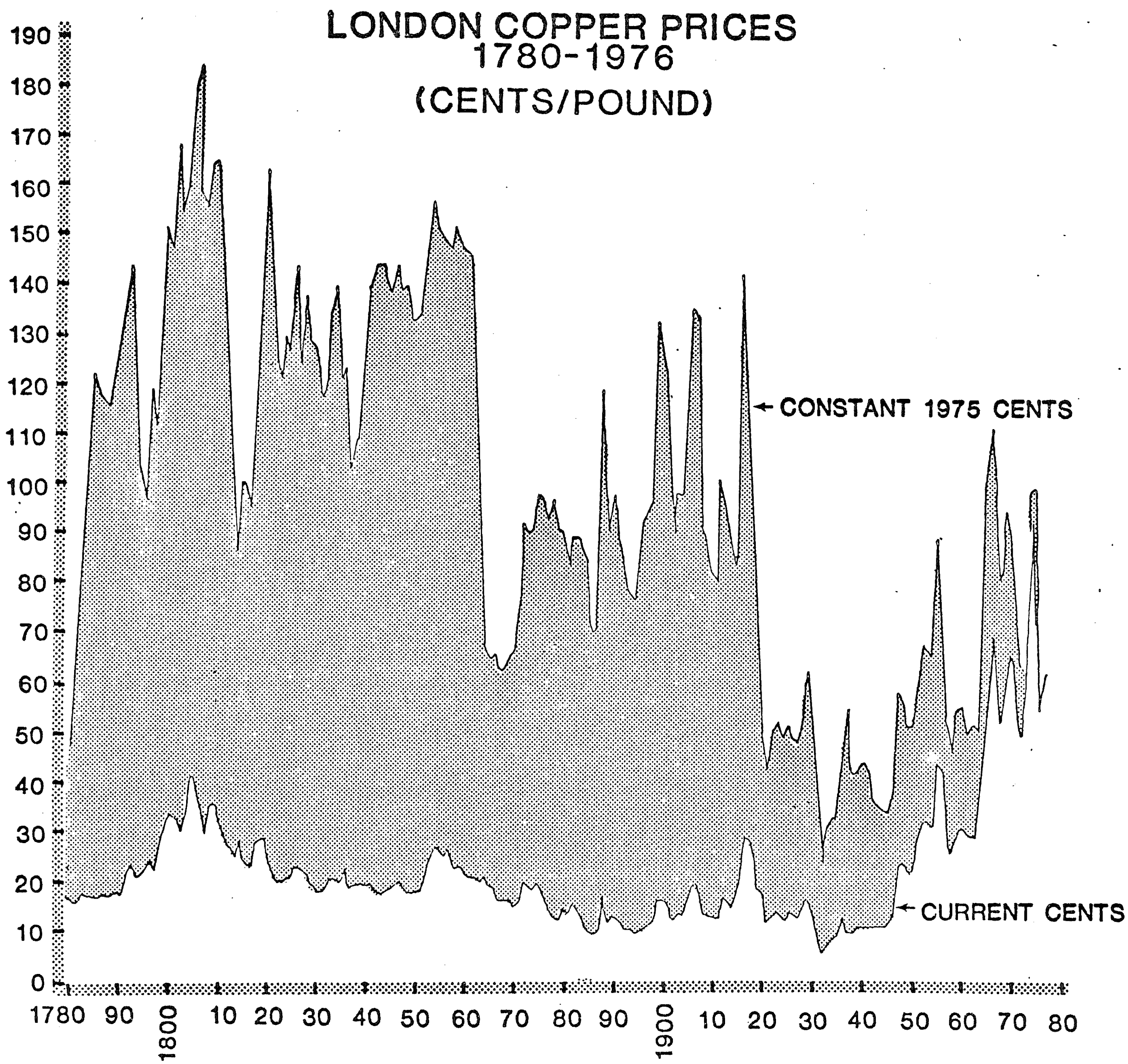
Countering the economic forces which would determine the price of copper in a completely free-market situation are the actions of some developing, copper-exporting countries. Third world nations which depend upon copper exports to generate foreign exchange and which enjoy lower than average production costs (especially in the area of pollution control, occupation health and safety and labor) are willing to produce and trade copper at less than the prevailing market prices. Thus, countries such as this exert a downward influence on the copper price.

Each of the long-term factors discussed above add to the current short-range hedge and speculation forces to chart the path of copper prices (see Figure 2). The trend over the past 200 years shows a roller-coaster effect which has been generally downward, indicating that substitution, lower intensity-of-use, and third-world pressures have dominated the market during this period.

Figure 2, Table 14

14.5.1.4 Copper Forecasts--Forecasts of future copper supply, demand, and price are available from a variety of sources. Information discussed above indicates

FIGURE 2



SOURCE: DOUGLAS, 1977

Table 14. U.S. producer copper prices, 1954-1977.

	ACTUAL PRICES	CONSTANT $1975 PRICES
	(U.S. producer prices, cents per pound)	
1954	29.5	62.9
1959	30.7	57.9
1964	32.6	57.1
1969	47.9	70.3
1970	58.2	81.1
1971	52.0	68.9
1972	51.2	65.2
1973	59.5	71.6
1974	77.3	84.5
1975	64.2	64.2
1976	69.6	66.2
1977	66.8	60.1

SOURCE: USBM 1977.

that total world resources of copper are adequate to meet long-term needs, therefore, the key to these forecasts is projected demand; as over time supply will adjust to meet demand and a corresponding price will result. Since the demand for copper is largely from economic sectors such as electrical and electronics, construction, and transportation, forecasts will be closely tied to forecasted changes in gross national product.

Presented below are forecasts from the U.S. Bureau of Mines (USBM), University of Pennsylvania professor Wilfred Malenbaum, the Commodities Research Unit (CRU), and the A.D. Little Company. Projections vary, due to the various sets of assumptions used and the forecasting methodology employed. For example, the USBM presents a straightline projection from the 1975 point on a 1965-1976 trend line of data. Malenbaum, on the other hand, indicates that in 1985 there will be a change in the slope of the demand schedules for copper, nickel, and cobalt. In these cases the annual change in demand for the minerals will be less for the period 1985-2000 than for the period 1975-1985. This reflects a continuing decreased intensity-of-use of these minerals in developed economies such as the United States. CRU and A.D. Little each use econometric models to forecast changes in demand and prices of these minerals. These models depend upon a myriad of historical data and assumptions about consumption behavior. A discussion of these forecast methods is beyond the scope of this study, but the reader is referred to the references for more information.

Domestic copper supplies are constrained in the short-term by the existing capacity of U.S. mines, smelters, and refineries. In the long-term, supplies are limited to existing and potential mineral resources and the price the market will bare before substitution of other commodities takes place.

USBM Forecasts--The USBM predicts that U.S. demand for copper will "most probably" grow at an annual rate of 3.5 percent leading to a probable demand of 4.6 million metric tonnes by the year 2000. The USBM cautiously attaches a "low" projection for 2000 of 3.5 million metric tonnes and a high forecast of 6.0 million metric tonnes.

Table 15

The USBM uses the 1975 point of a 1965-1975 trend line as its forecasting base for projecting U.S. demand.

U.S. supply for projection purposes is broken into two components by the USBM, primary (directly from minerals) and secondary (through recycling). Because of increased emphasis on recycling, secondary supplies are projected at a 5 percent annual growth rate while primary supply is forecasted at a 3 percent annual rate of increase. Contributions to primary supply from U.S. mines is projected at 90 percent of capacity by the USBM, the ratio which has prevailed in the recent past. At this rate U.S. copper mine production would most probably be 2,857,000 metric tonnes by the year 2000.

In 1976 U.S. domestic mine production was 1,602,000 metric tonnes (USBM 1977), while capacity was estimated to be 1,769,000 metric tonnes (CRU 1977).

Table 16

Projections can be modified by a number of factors. A greater-than projected demand would lead to increased prices in the short-term and ultimately result in

Table 15. Projections of U.S. copper demand (thousand metric tonnes of metal).

	2000 FORECAST RANGE		
1975	LOW	PROBABLE	HIGH
1,520	3,500	4,600	6,000

SOURCE: USBM 1977.

Table 16. U.S. "most probable" copper forecasts (1,000 metric tonnes of metal).

	SECONDARY DEMAND	PRIMARY DEMAND	PRIMARY PRODUCTION
1975	335	1185	1282
1985	726	1995	1814
2000	1451	3175	2857

SOURCE: USBM 1977.

a surge of supply to meet that demand. Increased prices would make many presently classified submarginal resources economically feasible, thus shifting them to the reserve classification and increasing the potential mineral supply. Increased prices would also lead to a spurt in exploration and improved technology, both of which would have the affect of increasing supply. The most likely perturbation to the supply curve is the potential of ocean floor mining of nodules containing high grades of manganese, copper, nickel, and other minerals. Should sea mining prove economical, by 1985 it is estimated that copper output from nodules could amount to 109,000 metric tonnes for a single mining venture (Tinsley 1977). This represents less than one percent of total world consumption predicted for 1985.

Also effecting the supply-demand relationship is the possibility of the CIPEC copper cartel exerting trade pressures. Zambia, Zaire, Peru, and Chile control a sizeable percentage of world production and have made overtures of strengthening the now-loose alliance which they have formed. CIPEC could artificially constrain copper supplies which would lead to increased prices. But these countries also need copper dollars for foreign trade purposes and it is unlikely that this cartel in the near-term will be very successful in controlling prices.

<ins>Malenbaum Forecasts</ins>--Forecasts of world demand for raw materials in 1985 and 2000 made by Wilfred Malenbaum of the University of Pennsylvania for the National Science Foundation are keyed to Gross Domestic Product (GDP) and Intensity-of-Use indicators for each area of the world. Malenbaum shows U.S. demand for refined copper to be 2,610,000 metric tonnes in 1985 and 3,202,000 metric tonnes by 2000. These figures are significantly lower than those projected

by the USBM, representing an annual growth in total demand of 2.6 percent from 1975 to 1985 and 1.9 percent from 1975 to 2000.

In order to understand why Malenbaum forecasts lower demand than the USBM "most probable" forecast, his assumptions about changes in GDP and Intensity-of-Use of metals must be examined. For the period 1975-1985 a GDP growth rate of 3.3 percent for the U.S. is projected. But for the longer period at 1975-2000 the growth rate is smaller, 3.2 percent. This represents a significantly smaller rate from 1985-2000 to achieve an overall 3.2 percent rate for the 1975-2000 period. Intensity-of-Use figures are projected to decline from the 1,681 metric tonnes per billion dollars of GDP in 1975 to 1,550 metric tonnes per billion dollars GDP in 1985 and 1,200 metric tonnes per billion dollars GDP by 2000.

Table 17

Malenbaum argues for a decreasing intensity-of-use for refined copper on two points. One, historically, developing countries have had a growing intensity-of-use figure but at some point (after they have become developed) this curve reaches a peak and then steadily begins to fall. The U.S. has passed the peak and is on the downward slope of this curve, while such areas of the world as Africa and Asia are on the upward slope of the curve.

Figures 3 and 4

Also, the demand for copper is highly susceptible to substitution. Aluminum and plastics are compatible replacements for many uses of copper.

Table 17. Malenbaum copper forecasts.

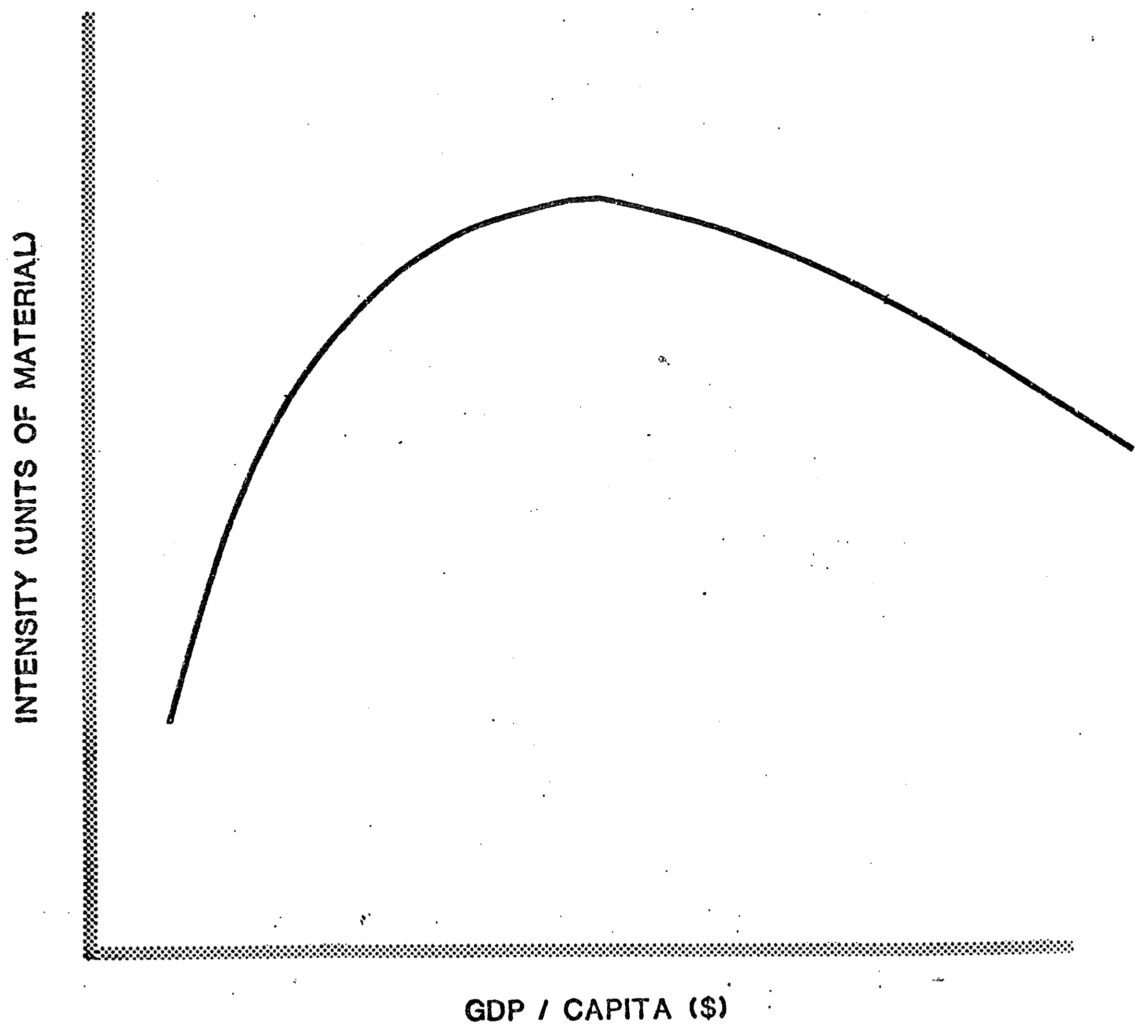
	U.S. PER CAPITA GROSS DOMESTIC PRODUCTION[a]	U.S. INTENSITY-OF-USE[b]	U.S. COPPER DEMAND[c]
1975	5250	1681	1886
1985	6959	1550	2610
2000	9495	1200	3202

SOURCE: Malenbaum 1977.

[a]1971 prices.
[b]Metric tonnes of copper per billion $ GDP, 1971 prices.
[c]1000 metric tonnes of metal.

FIGURE 3

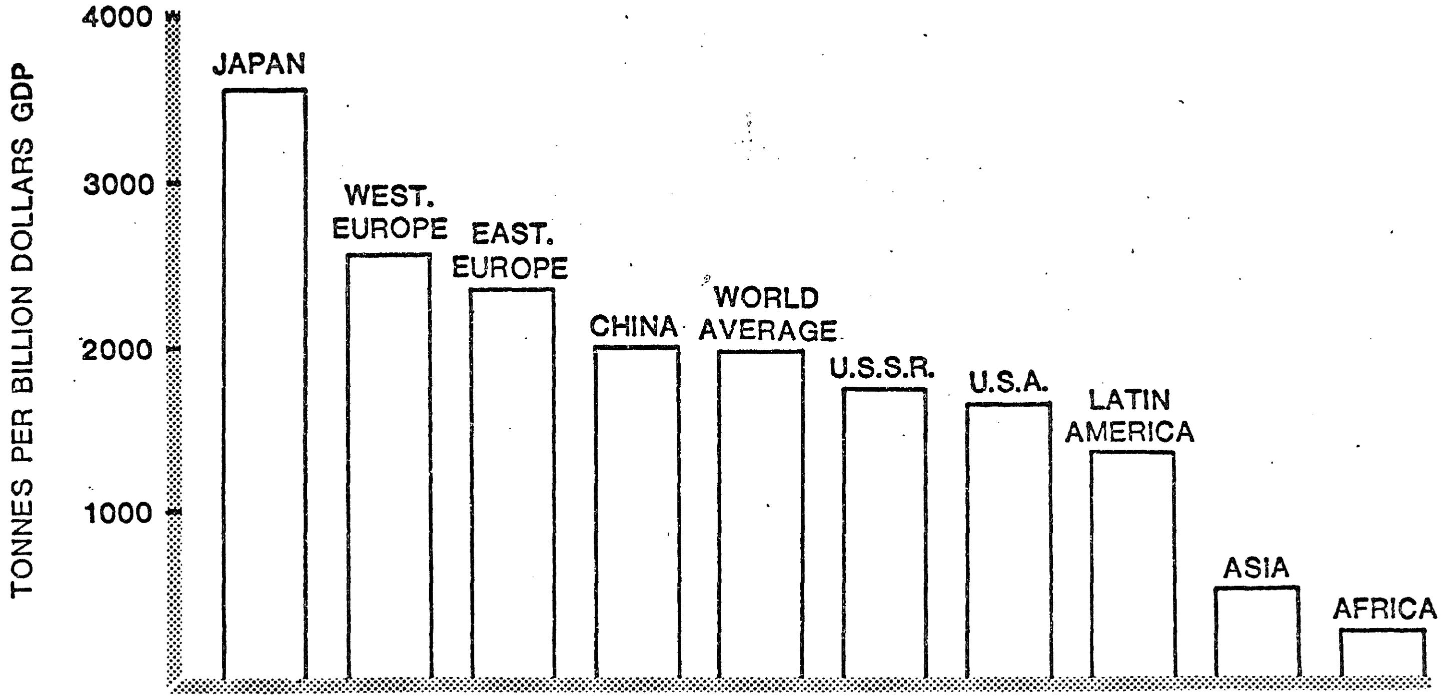
GENERALIZED INTENSITY OF USE



SOURCE : MALENBAUM

FIGURE 4

COPPER INTENSITY OF USE 1971-1975



SOURCE : MALENBAUM 1977

Commodities Research Unit Forecasts--Commodities Research Unit (CRU), a mineral commodity consulting firm under contract to the Regional Copper-Nickel Study provides forecasts of copper prices and U.S. mine production capacity to 1985.

CRU predicts that U.S. mine production capacity will reach 2,011,000 metric tonnes by 1985. This is about 11 percent greater than projections of copper demand made by the USBM, 1,814,000 metric tonnes for 1985, reflecting the historical idle capacity experienced by the industry.

Figure 5

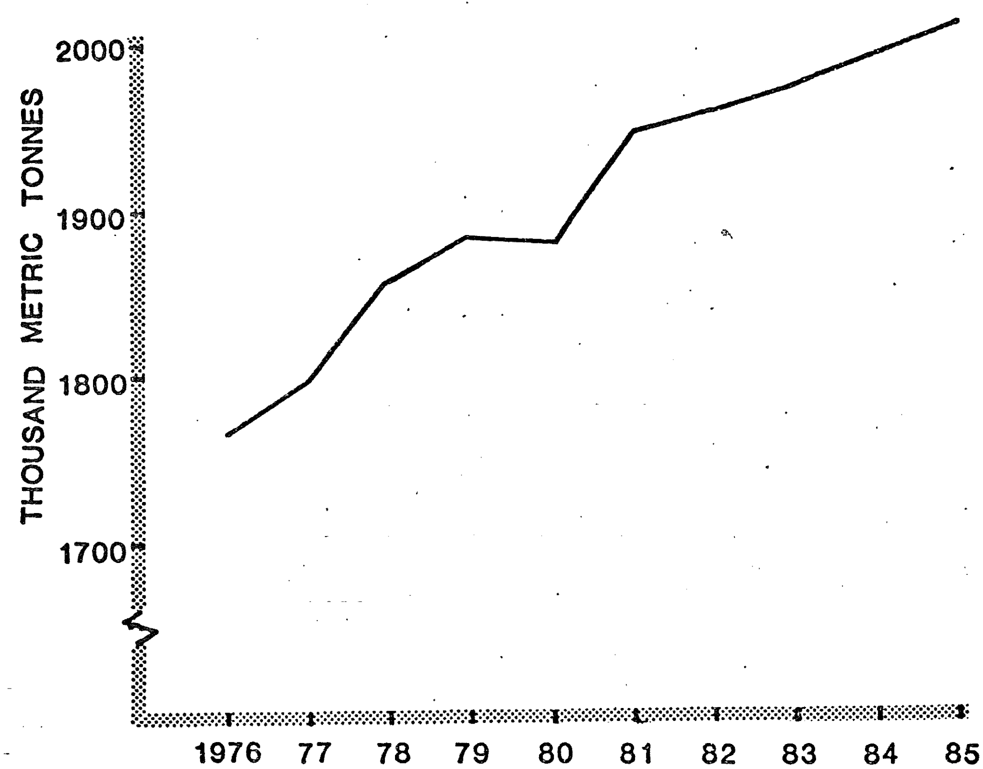
CRU projects a "most probable " price of 91 cents (in $1977) per pound of copper in 1985 with a forecasted price range of 144¢ to 87¢. This is the cash price for copper wirebar on the London Metals Exchange. The LME price generally leads the U.S. producer price in changes and is higher than producer prices during periods of excessive demand and lower during periods of weak demand. The LME price, except in the mid to late 1960's and 1973-1974 when LME prices leaped above producer prices by a large amount, has typically remained within 10 percent of U.S. producer prices.

Figure 6

A.D. Little Forecasts--The A.D. Little Company, in a study of the copper industry completed for the Federal Environmental Protection Agency, projects to 1985 such variables as total U.S. copper consumption, primary refined copper production, production from scrap, and copper prices.

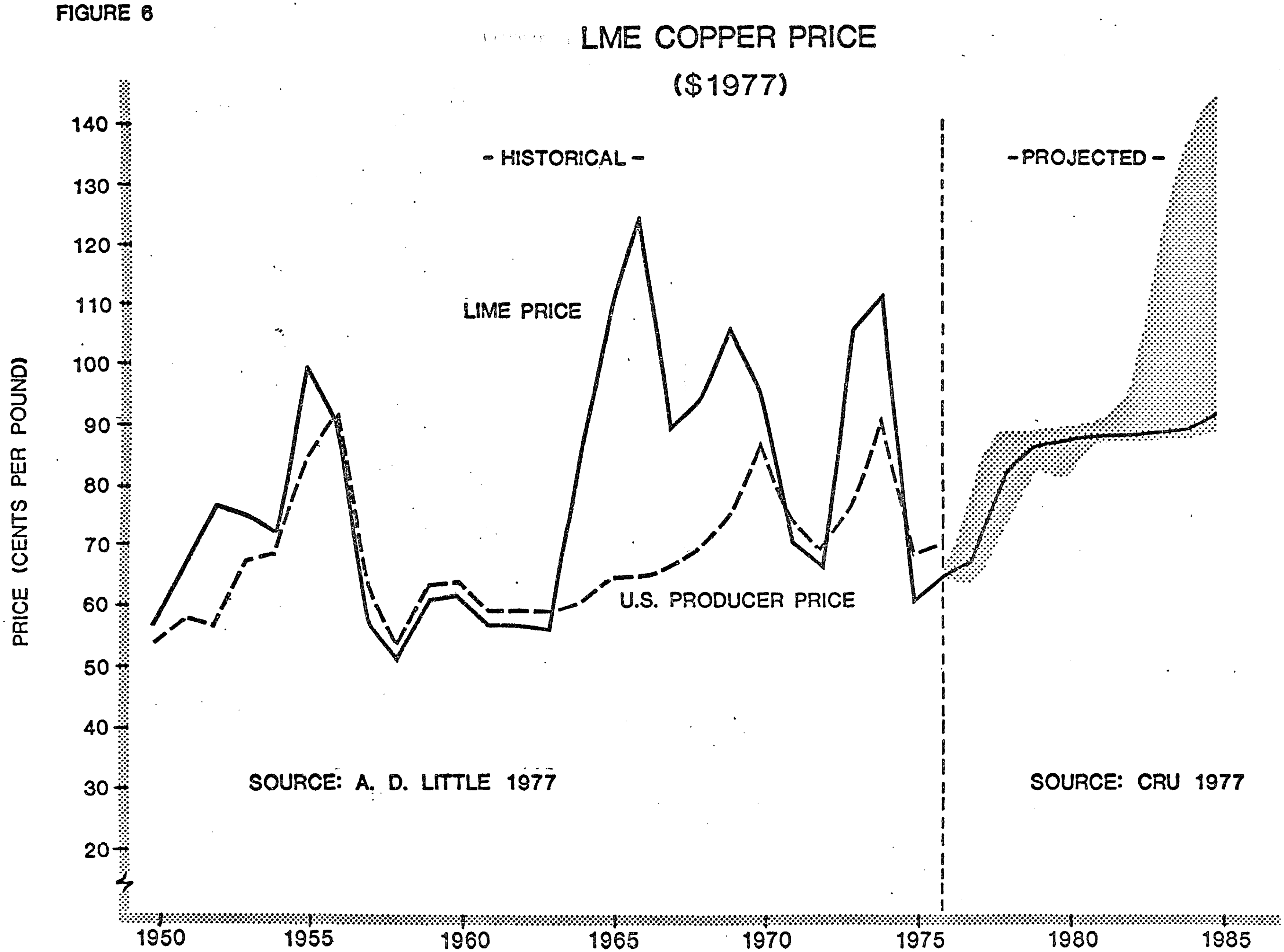
FIGURE 5

PROJECTED
U. S. COPPER MINE PRODUCTION CAPACITY



SOURCE : CRU 1977

FIGURE 6


LME COPPER PRICE
($1977)
PRICE (CENTS PER POUND)
140
130
120
110
100
90
80
70
60
50
40
30
20
- HISTORICAL -
- PROJECTED -
LIME PRICE
U.S. PRODUCER PRICE
SOURCE: A. D. LITTLE 1977
SOURCE: CRU 1977
1950
1955
1960
1965
1970
1975
1980
1985

A.D. Little projects U.S. consumption in 1985 to be 4,143,000 metric tonnes, an increase of 32 percent from the 1977 value of 3,134,000 metric tonnes.

Table 18. U.S. total copper consumption (000 metric tonnes).

1977	1979	1981	1983	1985
3133.8	3439.8	3652.9	3829.3	4143.2

These figures represent a declining growth rate from 1977 to 1983 and then an upswing to 1985.

Domestic production of refined copper by primary producers from all sources, according to A.D. Little, will increase by 30 percent from the 1977 value of 1,869,000 metric tonnes to 2,438,000 metric tonnes in 1985.

Table 19. U.S. primary copper production (000 metric tonnes).

1977	1979	1981	1983	1985
1869.1	1987.8	2099.5	2247.2	2438.5

This forecast indicates a declining growth rate from 1977 to 1981 but a more rapid rate from 1981 to 1985.

A.D. Little shows little or no growth in the production of refined copper from scrap and the total quantity of scrap generated. This is contrary to the assumed annual growth rate for use of scrap of 5 percent presented by the USBM.

Table 20. Projected copper production from scrap (000 metric tonnes).

1977	1979	1981	1983	1985
214.3	220.4	221.2	226.8	225.4

Projections by A.D. Little show that copper prices reached a low point in 1977 and should climb steadily until 1983 before dropping off to a 1985 price of 74.8 cents per pound of primary refined copper (in $1974). Using an inflator of 1.218 from the Department of Commerce Implicit Price Deflators to convert $1974 to $1977, A.D. Little's forecast of 74.8 cents per pound corresponds exactly with the price projected by CRU of 91 cents per pound of copper. A more optomistic price of $1.36 per pound (in $1977) by 1985 is offered by Chase Econometric Associates, Inc. (Adams 1979).

Table 21. Projected copper prices ($1974).

1977	1979	1981	1983	1985
56.4(68.7)*	68.9(83.9)	72.9(88.8)	76.6(93.3)	74.8(91.1)

*$1977 in ( ).

Summary

Because the forecasts presented here are from a variety of sources, different definitions, assumptions, and parameters are incorporated into the projections, making comparisons of the forecasts tenuous. Presented below is a matrix which shows the 1985 forecasts made by each of the four sources.

Table 22

Table 22. Summary of 1985 U.S. copper forecasts (1000 metric tonnes of metal unless otherwise noted).

	USBM	MALENBAUM	CRU	A.D. LITTLE
Per capita gross domestic product		$6,959		
Primary copper demand	1,995			
Secondary copper demand	726			
Total copper demand	2,721	2,610		
Total copper consumption				4,143
Primary copper production	1,814			
Primary production capacity			2,011	
Secondary copper production				225
Total copper production				2,439
Copper price			91¢	91¢

The figures shown above provide comparison for only a few elements. Forecasts of total demand for U.S. copper by the U.S.B.M. and Malenbaum are within 5 percent of each other at about 2.6 to 2.7 million metric tonnes. Malenbaum's forecast is lower than that of the U.S.B.M. due to his assumption about U.S. copper intensity-of-use, but it fits within the forecast range of the U.S.B.M. As indicated above, the figure projected for U.S. primary production capacity by CRU is approximately 11 percent higher than the demand for primary copper as predicted by the U.S.B.M. The difference would represent idle capacity within the industry in 1985. Historically, the industry has experinced idle capacity of the same magnitude. The 91 cent per pound copper prices as predicted by the econometric models of CRU and A.D. Little are, of course, identical. The projected increase in price reflects that the present imbalance of supply over demand should have begun to correct itself by 1985.

If demand for U.S. primary copper, as projected by U.S.B.M., is compared with the U.S.B.M. forecast for U.S. mine production in 1985, a 9 percent shortfall of domestic production is predicted. However, the CRU forecast of primary production is nearly identical to the U.S.B.M. projection of primary demand. This indicates that there will be very little change in the present U.S. copper import/export/domestic production relationship by 1985.

Consumption of copper, as forecast by A.D. Little, seems higher than would be expected in comparison with data from other sources. A reason for this lies in the baseline data used by A.D. Little versus the baseline used by the U.S.B.M., for example. The key to a consumption forecast is the pattern and level of industrial demand in the U.S. 1974 data from the U.S.B.M. shows total U.S. industrial demand to be 2.2 million metric tonnes with 51 percent of demand from the electrical sector. A.D. Little baseline data for the same year shows 2.8 million metric tonnes (a 27 percent difference) of industrial demand in the U.S. with only 33 percent of demand from the electrical sector. Understanding this divergence of data baselines aids in explaining why U.S. consumption of copper as projected for 1985 by A.D. Little seems inordinately high.

Comparing demand for secondary copper (recycled either in the manufacturing process or after end-use), as projected by the U.S.B.M. to the A.D. Little projection of secondary copper production indicates that the industry will not keep pace with the demand for secondary products. This may be explained by the lead time required in the mineral industry to adjust to changes in demand patterns. The U.S.B.M. figure reflects a 117 percent increase in demand for secondary copper in 10 years while A.D. Little projects only a 5 percent increase in secondary production from 1977.

According to CRU, there will be an expansion of 242,000 metric tonnes of mine production capacity from 1976 to 1985. Identified U.S. resources other than Minnesota are approximately 5.1 billion metric tonnes of copper ore with an average ore grade of .62 percent copper. The Minnesota resource of 4.0 billion metric tonnes of copper ore with an average grade of .66 percent copper, when added to other U.S. sources yields a total resource of 9.1 billion metric tonnes. Thus, the expansion requirements of U.S. copper producers will represent less than 3 percent of available domestic resources. In other words, given that potential resources become actual reserves, there will be no shortage of alternative projects open to copper producers in 1985. Even though Minnesota copper resources represent 44 percent of total identified resources, development competition from other alternative copper ventures will be stiff.

Table 23

The CRU projection of U.S. mine capacity (domestic copper supply) shows an annual growth of about 1.5 percent (see Figure 7). The U.S.B.M., on the other hand, projects that demand for U.S. primary copper production will grow at a 3 percent annual rate. The lower path of capacity expansion charted by CRU is in effect absorbing the idle capacity experienced by the industry in the mid 1970s. By 1985 the CRU and U.S.B.M. forecasts combine to indicate an 11 percent idle capacity for the industry, in line with historic trends.

Figure 7 shows what will happen to the demand/capacity relationship should the growth rates used for 1975-1985 continue to 2000. It also shows alternative rates of growth for capacity expansion.

Figures 7 and 8

Taking, for example the 2 percent growth curve of mine capacity, greater than the CRU forecast but less than the predicted growth rate of demand, it is shown that demand for U.S. primary copper will become greater than the U.S. capacity to provide primary copper in the late 1980s. Once this occurs the price of copper will undoubtedly rise, resulting in several possible scenarios. U.S. smelters and refiners may turn to imports as a source of copper, there may be increased effort to produce copper products from secondary copper or the increased copper price could boost the expansion of primary domestic capacity as once-marginal resources become economically viable with higher copper prices. The time lag necessary for the industry to respond is often up to 10 years. It

Table 23. U.S. identified copper resources.

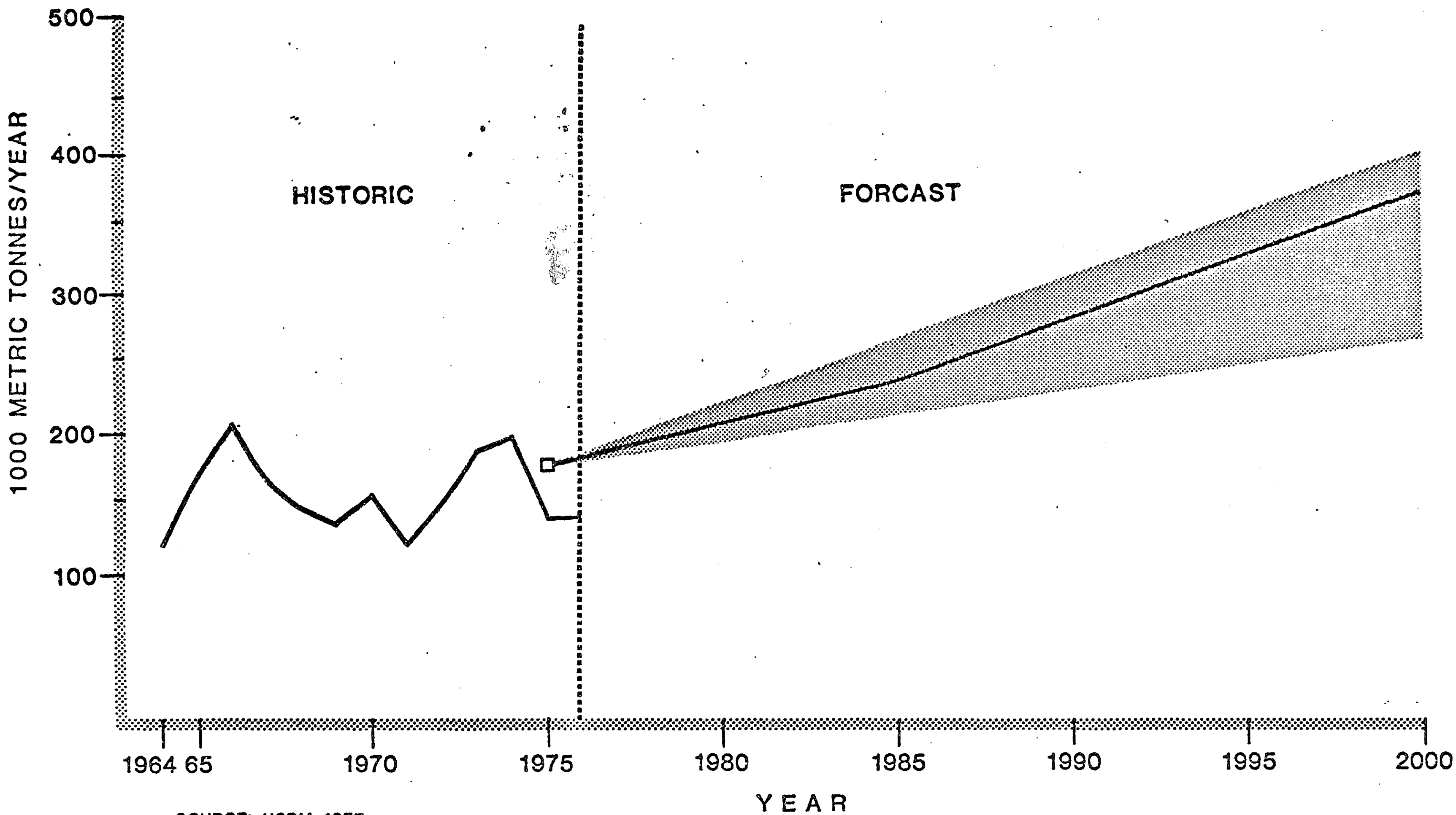
	RESOURCE (10^6 mt)	AVERAGE Ore Grade
Arizona	2,662	.63
Montana	1,498	.71
Nevade	925	.40
Wisconsin	67	.97
Total U.S.[1]	5,143	.62
Minnesota	3,991	.66

SOURCE: CRU 1977.

[1]Other than Minnesota.

FIGURE 8

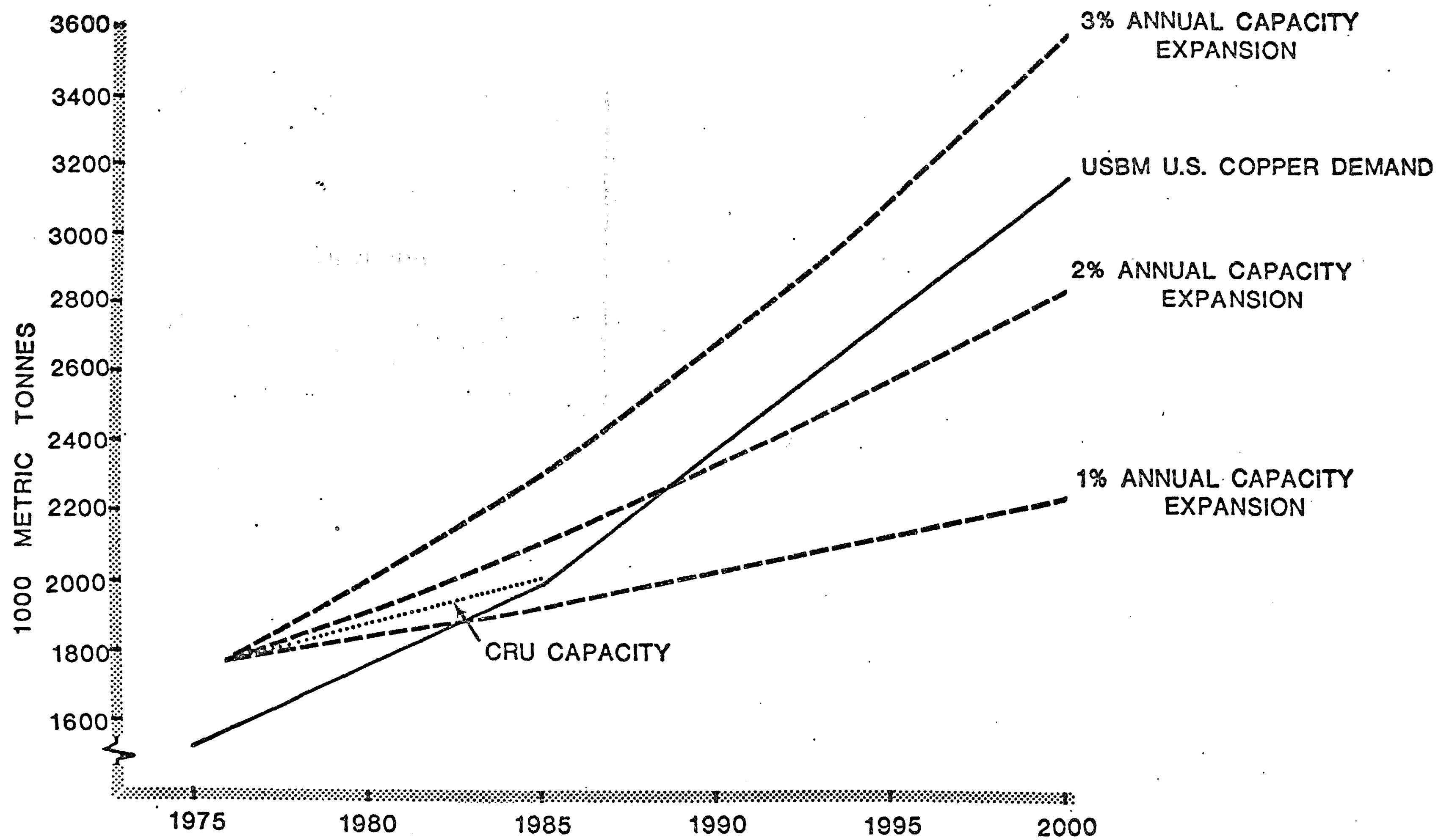
U. S. PRIMARY COPPER DEMAND



SOURCE: USBM 1977

FIGURE 7

PROJECTED U.S. DEMAND/CAPACITY RELATIONSHIP



is just such a demand/capacity situation that AMAX, for example, may be hedging against with its potential Minnesota operation.

A Minnesota mine, as described in Volume 2 of this report, would produce 84,600 metric tonnes of copper. This represents about 5 percent of the U.S.B.M. projected 1985 domestic primary copper production. More importantly, one Minnesota mine would contribute about 35 percent of the capacity increase projected by CRU for the period 1976-1985. In order to capture its share of expansion, a Minnesota project must compete economically with all the other identified resources in the U.S.

By the year 2000 demand for U.S. primary copper is expected to reach 3.2 million metric tonnes, an increase of 1.6 million metric tonnes over the U.S.B.M. 1975 projection base. Three Minnesota copper-nickel operations at that time would have a capacity of 254,000 metric tonnes of copper annually, or 16 percent of the projected increase from 1976 in U.S. primary copper demand. However, many copper development projects, including ocean-floor mining, will compete for their respective market shares of this expanding demand for domestically produced copper.

In sum, it is possible that U.S. primary copper demand may exceed primary capacity by the time a Minnesota operation is likely to be in the production stage. Minnesota owns a sizeable share of competitive, known U.S. resources and would be more subject to development should demand outpace capacity. A single operation in Minnesota would represent more than one-third the predicted capacity expansion by that time. Projecting to 2000, three Minnesota operations would result in a 16 percent share of U.S. primary copper demand.

14.5.2 Nickel

With the United States' only source of primary nickel scheduled to be depleted by 1990, the pressure for a domestic source of this strategic metal takes on increasing importance. Canadian companies dominate the nickel industry and represent a relatively safe, though increasingly parochial in attitude, source of the metal. However, in the ever competitive field of natural resources, the importance of domestic capabilities looms large.

In this light, Minnesota's copper-nickel resource represents the largest potential producer of nickel in the country. And because its production costs are in part underwritten by the production of copper, cobalt, and other precious metals, it appears that Minnesota nickel can be produced on very competitive terms relative to other sources

14.5.2.1 Supply--The U.S. supply of nickel is extremely dependent on foreign sources. Supplies of primary nickel are expected to be about 13,600 metric tonnes through 1985 when the only domestic source of nickel in Oregon is projected to be depleted. This represents only 5 percent of 1975 total supply of nickel in the U.S. (USBM 1977).

Most of the U.S. nickel imports come from Canada (33% of U.S. supply in 1975), with other large sources being New Caledonia (6.0% of supply in 1975), Norway (3.7% of supply in 1975), and the Dominican Republic (2.7% of 1975 supply).

Table 24

Table 24. U.S. nickel supply, 1965-76 (thousand metric tonnes of metal).

	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
Components of U.S. supply:											
Domestic mines	12.0	13.2	13.8	14.3	14.1	14.1	14.2	12.6	12.8	13.0	12.6
Secondary	57.2	47.4	33.2	64.4	44.2	57.2	61.2	59.8	58.5	37.7	42.6
Shipments of Government stockpile excesses	94.0	20.2	2.9	3.9	1.9	13.5	16.2	0.9	4.2	0.4	0.5
Imports	127.9	129.7	134.2	117.3	141.8	130.0	157.7	173.3	200.2	147.2	171.1
Industry stock, Jan. 1	12.8	40.4	35.9	33.7	28.9	22.4	52.0	70.7	64.7	79.2	92.9
TOTAL U.S. SUPPLY	303.9	251.9	220.0	233.7	230.9	236.3	286.8	317.3	340.3	277.5	319.6

SOURCE: USBM 1977.

From 1966 to 1976 domestic contributions were steadily about 13,600 metric tonnes, while imports rose from 127,900 metric tonnes in 1966 to 171,000 metric tonnes in 1976. During that period, imports peaked in 1974 at 200,200 metric tonnes.

Second only to imports as a component of annual nickel availability is the stock maintained by the industry. This has been a rapidly growing share of supply. In 1966 industrial stocks amounted to only 4.2 percent of total U.S. supply. By 1976 this share had risen to 29.1 percent, a sevenfold increase. This is explained by the decrease in demand for nickel by the industrial sectors of the economy, to be discussed below. Because supply has been greater than industrial demand in recent years, the surplus has been absorbed into industrial stocks. Growth in industrial stocks also represents an effort on the part of the suppliers to maintain a constant or increasing price.

Recycled nickel makes up a significant percentage of total U.S. supply. About 14 percent of supply (three times the primary production) is from secondary sources. This includes scrap generated in fabricating plants as well as scrap from obsolete goods and equipment.

In the past the U.S. has maintained a government stockpile of various forms of nickel for strategic and defense purposes. In 1966 the stockpile contained 94,000 metric tonnes, but by 1976 the stockpile had dwindled to only 454 metric tonnes. In 1976 the government set a new goal of 185,000 metric tonnes, but in 1977 the Administration called an indefinite halt to the acquisition and sale of nickel for stockpiles.

14.5.2.2 Demand--Industrial stocks make up a large portion of total U.S. demand at the present time. As mentioned above, nearly 30 percent of U.S. supply has been maintained as industrial stockpiles. Only in 1977 and 1978 have Canadian producers begun to cut back production in an effort to reduce current stocks.

An additional distribution of the U.S. supply of nickel is in the form of exports. In 1975 this amounted to only 2.4 percent of total available nickel. In 1976 exports more than doubled to 14,300 metric tonnes or about the equivalent of domestic primary production.

Demand by the industrial segments of the U.S. economy make up the largest share of the distribution of U.S. nickel supply. About 90 percent of the nickel consumed in the U.S. is used in alloys with other metals. Nickel's corrosive resistance, strength, and chemical properties make it extremely valuable in the manufacture of a wide variety of producer and consumer goods.

The largest demand for nickel from the industrial sectors is that of the transportation industry. Nickel in the form of stainless steels and other alloys is also consumed by the fabricated metal products, electrical, construction, machinery, and household appliances. Industrial demand since 1966 has actually decreased although it has been subject to a rapidly fluctuating pattern. Total 1976 demand of 193,400 metric tonnes is 27 percent less than the total industrial demand of 264,800 metric tonnes in 1966.

Table 25

Table 25. U.S. nickel demand, 1965-76 (thousand metric tonnes of metal).

	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
Distribution of U.S. supply:											
Industry stock, Dec. 31...	28.4	31.4	33.8	28.9	22.4	52.0	70.7	64.7	79.2	92.9	111.9
Exports..................	10.7	7.3	5.9	2.1	5.9	4.2	2.7	4.5	3.9	6.7	14.3
Industrial demand.........	264.8	213.2	180.3	202.6	202.6	180.1	213.4	248.1	257.2	177.9	193.4
U.S. demand pattern:											
Chemicals.................	19.4	23.6	20.3	31.1	30.3	26.9	31.9	37.4	39.0	25.4	28.2
Petroleum.................	10.6	12.8	11.2	15.7	16.1	16.2	19.3	22.4	23.7	16.8	16.9
Fabricated metal products	26.0	36.6	22.7	17.0	19.3	18.4	21.4	24.9	23.7	15.7	17.0
Transportation											
Aircraft................	27.6	15.0	22.0	13.5	12.2	12.6	14.7	17.4	15.4	10.8	16.4
Motor vehicles and equipment.........	33.0	21.8	30.0	21.2	24.2	19.8	23.9	27.4	26.7	19.5	20.6
Ship and boat building and repairs..	10.6	6.6	8.3	7.8	6.0	5.5	6.2	7.6	12.2	9.3	7.9
Total................	71.2	43.4	50.4	42.5	42.4	37.9	44.8	52.4	54.2	39.5	44.9
Electrical................	31.5	18.3	18.8	27.2	26.1	23.3	27.8	32.3	31.2	23.2	24.4
Household appliances......	26.2	16.7	17.0	12.4	13.2	12.3	15.0	17.4	19.7	11.5	13.7
Machinery.................	38.6	11.7	11.9	14.8	15.0	12.4	15.0	17.4	20.9	14.9	14.7
Construction..............	12.5	10.0	9.8	14.6	19.3	16.2	19.3	22.4	25.9	16.7	17.8
Other.....................	28.7	40.3	18.2	27.3	21.0	16.3	19.0	21.4	19.0	14.1	15.9
Total Industrial Demand	264.8	213.2	180.3	202.6	202.6	180.1	213.4	248.1	257.2	177.9	193.4
Total U.S. Primary Demand	207.5	165.8	147.1	138.2	158.5	122.9	152.2	188.3	198.7	140.1	150.7

SOURCE: USBM 1977.

A major reason for the decline in nickel demand over the recent past must be the effects of substitution. The rate of substitution of nickel with other metals in making alloys and with plastic coatings of materials previously using nickel alloys to resist corrosion most likely has more than offset the gains in consumption of producer and consumer goods made during this same period. Nickel demand is also felt to be extremely income elastic, meaning that consumers will delay purchases of nickel-containing items during a depressed economic period such as the last ten years (Cameron 1976).

In summary, like copper, demand for nickel can be seen to be closely tied to movements in the national economy, and demand for nickel can be reduced by substitution with other commodities. U.S. supply is highly dependent on Canadian and other imports with only about 5 percent coming from domestic primary production, and 14 percent from secondary production.

Table 26

14.5.2.3 Price--Nickel prices in constant dollars have increased substantially in the past 20 years. The 1976 average annual price of $2.09 per pound was 51 percent greater than the price of nickel in 1954. The period from 1954 to 1965 was marked by very stable prices, but between 1965 and 1968 nickel price increased dramatically, reflecting the boom in the national economy resulting from the Vietnam war. The price then stabilized until 1973, when it once again began to climb. However, since a peak price of $2.41 per pound in early 1977, the nickel price has declined steadily to a year-end 1978 price of $2.03 per pound (in current dollars).

Table 27

Table 26. U.S. Nickel demand, production, 1954-1976 (thousand metric tonnes of metal).

	U.S. PRIMARY DEMAND	U.S. PRIMARY PRODUCTION
1954	76.1	.7
1959	83.7	10.5
1964	119.8	11.1
1969	138.2	14.3
1970	158.5	14.1
1971	122.9	14.1
1972	152.2	14.2
1973	188.3	12.6
1974	198.7	12.8
1975	140.1	13.0
1976	144.9	13.1

SOURCE: USBM 1977.

Table 27. Nickel price, 1954-1978.

	ACTUAL PRICE*	CONSTANT $1975 PRICE*
1954	64	138
1959	74	139
1964	79	138
1969	128	188
1970	128	178
1971	133	176
1972	140	178
1973	153	184
1974	174	190
1975	203	203
1976	220	209
1977	230	204
1978	208	171

SOURCE: USBM 1979.

*Average annual price, cents per pound.

14.5.2.4 Nickel Forecasts--Forecasts of future nickel supply, demand, and price are available from a number of sources. As mentioned above, nickel demand is closely tied to movements in the national economy. Use of national economic indicators such as Gross National Product, Federal Reserve Board's Index of Industrial Production, and the Index of Gross Private Domestic Investment to forecast change in mineral commodities demand is common.

Presented below are nickel forecasts from the U.S. Bureau of Mines (USBM), University of Pennsylvania professor Wilfred Malenbaum, and the Commodities Research Unit (CRU). Projections vary, in general, due to the various sets of assumptions used and the forecasting methodology employed. The experience discussed with copper forecasts applies equally to the projection of nickel parameters. Nickel forecasts suffer also because there is relatively less data on nickel than exists for copper and other minerals which are more actively produced in the U.S. The dominance of the nickel industry by INCO and other Canadian firms and active participation in the industry by the U.S. Government also makes interpretation of the data on nickel much more tenuous.

INCO dominates the nickel industry and sets the price of nickel with other firms falling in line. The U.S. government was responsible for the development of much nickel capacity in the 1950s by offering long-term contracts and premium prices to competitors of INCO in an effort to boost the North American industry and reduce INCO's dominance.

Domestic nickel reserves, based on present prices, are extremely limited so that growth in nickel supply will, by necessity, come from changes in secondary (recycled) production and from imports. Increased prices could significantly increase domestic reserves with the reclassification of Minnesota copper-nickel and other known deposits from resources to reserves. Developments in sea bed mining of manganese nodules high in nickel content could alter the supply outlook if investment and political problems can be overcome.

USBM Forecasts--The Bureau of Mines predicts a growth in total U.S. nickel demand at an annual rate of 3.1 percent between 1975 and 2000. Primary nickel demand (demand for production from mines) is projected at 3.0 percent annual growth, while the projected annual growth rate for secondary (recycled) demand is 3.5 percent. At these rates, probable total nickel demand for 2000 would be 526,000 metric tonnes.

Table 28

The U.S. growth rates are significantly lower than those for world nickel demand, reflecting the developed nature of the U.S. economy.

The USBM predicts that at the present rate of production, the only U.S. domestic nickel reserves at Riddle, Oregon, will be exhausted in 10 to 12 years (USBM 1977). This means that unless additional reserves are discovered--Minnesota's copper-nickel resource, others in California, Montana and Alaska and sea bed mining are potential reserves--the U.S. will be completely dependent on imports of nickel and secondary production. The USBM offers no projection of supply from secondary sources.

If these potential reserves prove feasible, the USBM projects that primary supply will be 245,000 metric tonnes per year in 2000. This would represent 65

Table 28. Projection of U.S. nickel demand (thousand metric tonnes of metal).

	2000 FORECAST RANGE		
1975	LOW	PROBABLE	HIGH
178	381	526	580

SOURCE: USBM 1977.

percent of total U.S. primary demand, or more than 7 times the contribution made by domestic primary production in 1975.

Despite the expected growth in domestic primary production, the figures indicate that the demand for U.S. produced nickel will outrun anticipated production by a considerable margin. This would create a favorable market for the development of domestic nickel capacity in Minnesota.

If three operations of the magnitude described in Volume 2 of this report are in operation by the year 2000, Minnesota would produce 46,200 metric tonnes of nickel annually. Minnesota, then, would account for nearly 20 percent of the estimated domestic primary supply and 12 percent of U.S. primary demand. This indicates that development of Minnesota's copper-nickel deposits would have a significant impact on the U.S. nickel industry.

Table 29

Malenbaum Forecasts--Wilfred Malenbaum, of the University of Pennsylvania, offers forecasts of demand for nickel based on assumptions about growth in GDP and Intensity-of-Use for nickel. U.S. demand for nickel is projected by Malenbaum to be 280,100 metric tonnes in 2000. As is the case with copper, the Malenbaum projection for total U.S. demand is significantly lower than the forecasts of the USBM (Table 26). His annual growth rate for the period from 1975 to 1985 is 2.2 percent and declines to 2.0 percent for the longer 1975 to 2000 time period.

Table 29. U.S. nickel demand, production forecasts.

	U.S. SECONDARY DEMAND*	U.S. PRIMARY DEMAND*	U.S. PRIMARY PRODUCTION*
1975	37.7	140.1	13.0
1985	90.7	240.4	90.7
2000	149.7	376.4	244.9

SOURCE: USBM 1977.

*1000 metric tonnes of metal.

The basis for Malenbaum's lower demand projection lies in his assumptions about GDP and Intensity-of-Use. The U.S. GDP growth rate of 3.2 percent for 1975-2000 versus the 3.3 percent rate for 1975-1985 represents a significant slowing of growth after 1985. As well, the Intensity-of-Use for nickel in the U.S. declines as the country becomes more and more developed (as mentioned above).

Table 30

Malenbaum projects a declining Intensity-of-Use for the U.S. and the world through 2000. Also, many other areas of the world use nickel much more intensely than does the U.S. Japan, for example, has nearly three times the use of nickel per billion dollars of GDP than the U.S.

Commodities Research Unit (CRU) Forecasts--CRU makes projections of nickel consumption and prices for 1985.

United States nickel consumption is forecast by CRU to reach 293,500 metric tonnes by 1985. This represents an annual growth rate of 3.4 percent from 1974 to 1980 and 4.4 percent from 1980 to 1985. The CRU forecast is 11 percent lower than the demand projection made by the USBM, but 39 percent higher than the U.S. demand predicted by Malenbaum.

Table 31

CRU projects a declining real nickel price through 1985 largely due to severe world excess nickel production capacity resulting in forecasted supply/demand imbalance.

Table 30. Malenbaum nickel forecasts.

	U.S. PER CAPITA GROSS DOMESTIC PRODUCTION[a]	U.S. INTENSITY-OF-USE[b]	U.S. NICKEL DEMAND[c]
1975	5250	143.1	160.5
1985	6959	125.0	210.5
2000	9495	105.0	280.1

SOURCE: Malenbaum 1977.

[a] 1971 prices.
[b] Metric tonnes of metal per billion $ GDP, 1971 prices.
[c] 1000 metric tonnes of metal.

Table 31. Projected U.S. nickel consumption (1000 metric tonnes of metal).

	U.S. CONSUMPTION
1976	187.3
1977	202.6
1978	214.9
1979	226.1
1980	237.1
1981	247.5
1982	258.4
1983	269.7
1984	281.4
1985	293.5

SOURCE: CRU 1977.

Table 32

Summary

Because the forecasts presented here are from a variety of sources, using different data, assumptions, and looking at different parameters, comparisons are difficult to make. Below is a matrix which summarizes the projections for 1985 made by each of the sources. There is little overlap to provide comparison.

Table 33

The only comparison of available forecasts which can be made is of total U.S. nickel demand for 1985. The U.S.B.M. forecast is more than 50 percent higher than the projection made by Malenbaumn, reflecting the Malenbaum assumption of a decreasing intensity-of-use of nickel for the U.S. Total U.S. demand, as forecast by U.S.B.M., is 13 percent higher than the CRU projection of total U.S. nickel consumption.

Of interest to Minnesota is the wide difference between U.S. primary nickel demand and U.S. primary nickel production. Demand is more than 2½ times the production anticipated by the U.S.B.M. in 1985. Excess demand will spur an increase in production capacity and Minnesota possesses approximately 80% of the identified U.S. nickel resources.

Table 34

Table 32. Nickel price forecast.

	Current prices	$1977 prices
1977	2.28	2.04
1978	2.42	2.04
1979	2.64	2.10
1980	2.76	2.07
1981	2.76	2.06
1982	2.96	2.04
1983	3.20	2.02
1984	3.36	2.00
1985	3.15	1.99

SOURCE: CRU 1977.

Table 33. Summary of 1985 U.S. nickel forecasts (1000 metric tonnes of metal unless otherwise noted).

	USBM	MALENBAUM	CRU
Per capita gross domestic product		$6959	
Primary nickel demand	240.4		
Secondary nickel demand	90.7		
Total nickel demand	331.1	210.5	
Total nickel consumption			293.5
Primary nickel production	90.7		
Nickel price			199¢

Table 34. U.S. identified nickel resources.

	RESOURCE (10^6 mt)	AVERAGE Ore grade
Alaska	20.5[1]	.32
California	.1[1]	1.50
	27.0[2]	.71
Colorado	4.6[1]	.46
Maine	.9[1]	.60
Montana	90.7[1]	.40
North Carolina	.9[2]	1.0
Oregon	51.9[2]	.89
Pennsylvania	.7[1]	.69
Puerto Rico	181.4[2]	.58
Washington	.7[1]	.51
	26.7[2]	.60
U.S.Total[3]	406.1	.58
Minnesota	4,400.0[1]	.20

SOURCE: CRU 1977.

[1]Sulfide resources.
[2]Oxide resources.
[3]Other than Minnesota.

The gap between 1985 projected demand and production, 150,000 metric tonnes, represents less than 2 percent of U.S. resources. A single Minnesota mine operating in 1985 is expected to produce 15,400 metric tonnes of nickel or approximately 10 percent of the anticipated production shortfall. Since Minnesota controls a tremendous share of U.S. nickel resources the potential for Minnesota development is very high.

The key to development of Minnesota nickel resources is more-than-likely the attitude of the industry toward development of domestic nickel production capacity. Should the industry feel the necessity to have a domestic source of nickel, Minnesota is a prime candidate for development. Minnesota controls most of the U.S. resource and the nickel production costs, as estimated above, are very attractive. Ocean mining of nickel bearing nodules appears to offer Minnesota its greatest competition for a share of the expected nickel production capacity expansion, but Minneosta's production costs appear more favorable.

14.5.3 Cobalt

Current United States dependence on foreign sources for its supply of cobalt places Minnesota's resource in national importance. Because of its relationship with copper and nickel in the Minnesota ore body, the cost of producing cobalt may be underwritten by the production of the other metals, thus making the production of cobalt in Minnesota competitive with other sources. Production of Minnesota's cobalt will make the U.S. mineral markets much less subject to the whims and vagaries of foreign mineral producers.

14.5.3.1 Supply--The United States is almost entirely dependent on foreign sources for its supply of cobalt. Currently, there is no cobalt being mined in the U.S., and in 1976 only 1 percent of total supply came from secondary (recycled) production. In 1976, about two-thirds of the U.S. cobalt supply originated in the Zambia-Zaire area of Africa, with other supply from Finland, New Caledonia, Canada, and other countries.

The U.S. government maintains a stockpile of cobalt, with a goal of 84.4 million pounds (nearly twice the current balance) announced in 1976. Previous to this date, the excesses from the stockpile were used to modulate the supply of cobalt and constituted an important source of supply in the U.S. (28% in 1976).

14.5.3.2 Demand--Cobalt has many important and strategic properties and is used as an alloy in materials to provide strength, corrosion-resistance, and magnetization. Although similar to and often substituted for nickel, the demand for cobalt operates independently of nickel and copper. Cobalt's major end uses are in the electrical, transportation, machinery, paints, ceramics, and chemical segments of the economy.

In 1976 total U.S. cobalt demand was over 13,800 metric tonnes, representing a 33 percent gain from the previous year and near recovery to the peak demand of 1974.

Tables 35 and 36

14.5.3.3 Price--Because the supply of cobalt is associated very closely to the production of copper and nickel, yet the demand for cobalt operates independently of its host metals, the recent slump in the production of copper and nickel has resulted in dramatic increases in the price of cobalt. In the last

Table 35. U.S. cobalt supply, 1965-76 (thousand pounds of metal).

	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
Components of U.S. supply:											
Domestic mines	1,215	1,168	1,176	1,003	697	690	----	----	----	----	----
Secondary	48	120	143	328	69	125	197	264	270	342	329
Shipments of Government stockpile excesses	762	6,189	4,953	6,007	5,162	1,683	5,945	8,569	8,936	6,346	6,698
Imports	18,823	8,215	9,068	12,911	12,417	10,912	13,915	19,238	16,122	6,608	16,487
Industry Stocks, Jan. 1	3,600	6,400	6,552	5,888	5,128	5,733	5,235	4,534	9,184	9,467	6,902
TOTAL U.S. SUPPLY	24,448	22,092	21,892	26,137	23,473	19,143	25,292	32,605	34,512	22,763	30,416

SOURCE: USBM 1977

Table 36. U.S. cobalt demand, 1965-76 (thousand pounds of metal).

	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
U.S. demand pattern											
Nonmetal:											
Paints..................	1,451	1,044	1,451	1,285	2,152	2,042	2,323	2,646	2,807	1,965	2,943
Chemicals..............	753	696	882	1,382	538	707	1,270	1,635	1,959	1,523	1,783
Ceramics & glass.......	1,580	1,135	1,281	858	1,890	1,768	1,982	2,228	2,331	1,630	2,348
Total Nonmetal	3,784	2,875	3,614	3,525	4,580	4,517	5,575	6,509	7,097	5,118	7,074
Metal:											
Transport.: Aircraft...	4,482	3,575	2,544	4,046	3,297	2,518	4,294	4,023	5,290	2,636	3,458
Electrical............	5,387	4,160	5,100	4,024	4,589	3,633	6,069	6,460	5,628	3,166	5,513
Machinery:											
Machine tools.........	2,152	1,628	1,616	1,911	1,882	1,376	1,717	2,449	2,853	1,356	1,537
Construc. machinery...	1,685	1,623	998	1,268	1,179	1,080	1,190	2,034	2,211	1,355	1,608
Total	3,837	3,251	2,614	3,179	3,061	2,456	2,907	4,483	5,064	2,711	3,145
Coating & plating.....	---	---	---	3,351	---	---	---	---	---	---	---
Other.................	458	1,479	712	1,387	735	419	620	637	618	425	611
Total Metal	14,164	12,465	10,970	15,987	11,682	9,026	13,890	15,603	16,600	8,938	12,727
Total U.S. primary demand (total demand less secondary supply).........	17,900	15,220	14,441	19,184	16,193	13,418	19,268	21,848	23,427	13,714	19,472
Total U.S. demand for primary metal.............	14,116	12,345	10,827	15,659	11,613	8,901	13,693	15,339	16,330	8,596	12,398

SOURCE: USBM 1977.

15 years the price for a pound of cobalt had more than tripled to $5.20 in 1977. By January, 1979 the price has increased to $20.00.

Table 37

14.5.3.4 Cobalt Forecasts--The USBM provides forecasts for cobalt demand and supply.

The USBM forecasts a "most probable" demand for cobalt of 39.4 million pounds by 2000, an annual growth rate of 2.9 percent for the U.S. The growth rate for the world is projected at 3.3 percent per year. In the short-run, unless new copper and nickel developments are undertaken, demand will outrun supply and cause price to continue to climb.

As the price of cobalt rises, resources in the United States may become economically feasible to mine. The potential of sea bed mining of cobalt in manganese nodules looms large in the supply picture after 1985. Secondary production has the potential to provide up to ten percent of total U.S. supply in the future.

By 1985 the USBM predicts domestic primary production of 15 million pounds of cobalt from the following sources:

Oregon	5 million pounds
Idaho	3 million pounds
Minnesota	2 million pounds
Pacific Ocean	5 million pounds

Table 37. Cobalt price, 1954-1978.

	ACTUAL PRICE*	CONSTANT $1975 PRICE*
1954	2.60	5.54
1959	1.77	3.34
1964	1.50	2.63
1969	1.89	2.77
1970	2.20	3.06
1971	2.20	2.92
1972	2.45	3.12
1973	3.00	3.61
1974	3.46	3.78
1975	3.98	3.98
1976	4.44	4.22
1977	5.58	4.98
1978	11.53	9.56

SOURCE: USBM 1979.

*Average annual price, dollars per pound.

The value of cobalt production shown here for Minnesota is equivalent to half the output of one 100,000 metric tonnes/year copper-nickel refinery. It is likely that this level of development could be established in Minnesota by 1985 to 1990.

In summary, cobalt presents an extremely volatile picture due to several reasons. There is no domestic primary production at present, though rising cobalt prices could make known resources feasible for mining. The supply of cobalt is dependent on the production of copper and nickel. But because cobalt demand functions independently, rapidly-rising prices during periods of copper and nickel slump could result. Decreasing prices during periods of copper and nickel production booms could also result. In addition, ocean mining has the potential to provide a sizable share of supply should political and technical problems be solved.

With the increase in cobalt supply resulting in any ocean mining operation would come a concomitant slump in cobalt price. This would in turn make the potential of land-based cobalt-producing operations much less attractive.

Malenbaum Forecasts--Forecasts of demand for cobalt by Wilfred Malenbaum of the University of Pennsylvania show a demand for cobalt of 16,608 metric tonnes in the U.S. by 2000. Malenbaum makes his projections on the basis of a rising gross domestic product (GDP), but a declining Intensity-of-Use. His projections indicate that population and GDP overwhelm the decline in use of cobalt to produce a dramatic growth in demand for the metals.

Table 38

14.6 SUMMARY

Demand for each of these metals has been shown to be closely related to industrial activity. Past patterns have been generally steady and strong. The future looks bright in spite of inroads made by substitution, with the USBM projecting a 3.5 percent annual growth rate for copper demand through the year 2000, an annual nickel growth rate of 3.1 percent and 2.9 percent for cobalt. In each case the growth rate for the United States, presently the leading worldwide consumer of each of these commodities, is expected to be less than the worldwide average. This is corroborated by the decreasing intensity-of-use for the U.S. as predicted by Professor Malenbaum in his work. However, the U.S. will remain the largest free-economy world market for these commodities.

The picture of mineral supply is not quite so clear, nor is it as easily determined because it depends on the ability of mineral development companies to, first of all, find mineral resources and then to produce the metal economically. The U.S. is presently the world's largest supplier of copper, producing nearly as much as it consumes. But for nickel and cobalt, U.S. production at present is quite small. The nickel market is dominated by Canadian firms while about two-thirds of U.S. cobalt supply comes from Zambia and Zaire, an extremely volatile source of the metal. In the U.S., recycling of these metals represents a significant and growing source of supply.

Prices, of course, represent the interaction between demand and supply. Presently, the copper and nickel prices are very depressed while cobalt, because its supply is closely tied to copper and nickel production yet independent in demand, is doing well. Copper price is forecast by CRU to increase to about 91 cents per pound (constant $1977) compared to its present price of about 70 cents. Nickel, on the other hand, is predicted by CRU to decline in real terms to $1.99 per pound ($1977) from its current price of about $2.05 per pound. Cobalt is presently at about $12 per pound, a phenomenal increase in the last 20 years.

If the desire to develop domestic sources of these metals takes hold, Minnesota represents a significant and highly competitive resource. Three Minnesota operations the size of those hypothesized in Volume 2 would represent 8, 12, and 31 percent, respectively, of the predicted U.S. primary copper, nickel, and cobalt demand for the year 2000.

It appears likely that, because of the variety of metals available in the ore which may be credited against the production costs of any one metal, Minnesota metals can be economically produced at costs competitive with other potential new sources of the minerals. As described above, copper can be produced at about 65 cents per pound, with credits for nickel and precious metals, compared with a current price of about 70 cents per pound. Nickel is predicted to have production costs of about 50 to 75 cents per pound compared with a current price of about $2.05 per pound.

These factors indicate that Minnesota's copper-nickel resource is a relatively attractive development possibility. It represents a sizable share of the nation's copper, nickel, and cobalt resources. Even though these markets are international in nature, there is a strong demand for domestic primary minerals and Minnesota's minerals represent a significant source of supply to meet that demand.

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