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LONGER-TERM DOMESTIC SUPPLY PROBLEMS FOR NONRENEWABLE MATERIALS WITH SPECIAL EMPHASIS ON ENERGY-RELATED APPLICATIONS*†

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Most of the remarks made by the other three speakers have been concerned with short-term or, at most, intermediate-term, nonfuel resource problems, that is, those problems that we will be dealing with through the remaining 20 years of this century. I would like to comment on the longer term view, which I will define as being some period after the year 2000. In addition, I would also like to make some comments on nonfuel resources as related to energy production and use. Since the newer energy alternatives — breeder, nuclear fusion, advanced solar, etc. — cannot make major impacts until the next century, they also come under longer term considerations.

At best, longer-term problems and their potential solutions can, at this time, only be seen dimly and evaluated by intellectual "guesses." Nevertheless, general trends can be understood with present knowledge. Perhaps the greatest value of such longer term assessments is to provide guidance to decision makers to help them avoid making short-term decisions that will later prove to have been wrong in the longer term. It will be my task here to examine in a comprehensive way how materials are used in present and future energy production and use. I will discuss several problem areas (Fig. 1) that need our attention, including (1) by-products production, (2) import limitations, (3) possibilities for substitution and recycle, (3) elements whose uses can be expected to accelerate rapidly, (4) alternatives to presently conventional resources, (5) the role of synthesis, and (6) the adequacy of the data base available to resource analysts. In each case, I will point out a government action that might be effective in helping to solve the respective problem.

A typical example of conflict between the short- and long-term view is given in Fig. 2 for copper vs aluminum. On the one hand it now takes about four times as much energy to produce a ton of aluminum as a ton of copper from their respective ores. Thus, because of the current energy "crisis," there exists a tendency to urge greater production of copper and lesser amounts of aluminum to conserve energy. Further, even though USBM world resource-to-demand ratios for both copper ore and bauxite are of the same order of magnitude (but less so for copper using USGS estimates), domestic copper ore is plentiful, and domestic bauxite is relatively scarce.

Thus, promotion of greater use of copper on import independence grounds is also likely. By the year 2000, however, it is estimated that domestic recoverable copper-ore grade will decrease by half, or more, while bauxite grade will decrease to a lesser extent. Thus in 20 years, only about twice as much energy will be needed to produce a ton of copper vs a ton of aluminum. Although some alternative copper resources such as seafloor manganese nodules will probably be in use by the year 2000, the opportunity for aluminum resource expansion is very much greater. Domestic resources of anorthosite are very large, and the availability of kaolinite and other high aluminum clays are near infinite. Technology development is far along for use of both alternative resources, and costs are unlikely to be more than 10 to 15% higher than with use of bauxite. In addition, fly-ash wastes from coal-fired power plants (and in the future coal conversion plants) already contain more than enough aluminum to meet domestic aluminum demands and technology is now being developed at USBM, at ORNL, and elsewhere to use it as another alternative aluminum raw material. Use of fly ash has the added advantages of being a "free" raw material and of answering a serious national solids waste (and perhaps toxic metals waste) problem.

Finally, it should be noted that the energy requirement for recycled copper is 6 to 11% of that needed using current copper ores, but that the corresponding value for aluminum recycle is only 2 to 3% of that needed using bauxite. Since energy for recycle is independent of time, the percentage differences between the two recycle energy values will increase in the future. This comparison of copper and aluminum shows rather vividly how short-term policy decisions based in this example only on energy requirements, import dependence, and current estimates of resources can be reversed in the longer term based on more complete appraisals.

Turning now to uses of materials in current energy production and utilization, Fig. 3 shows the percentage use for 21 materials whose direct energy-related domestic uses constitute 40% or more of the total consumption. The general class of energy-related application, as well as special considerations for these materials, is also given in Fig. 3. If one examines this figure carefully, one realizes that the energy-related applications are considered in a broad way. For example (Fig. 4), use of barite in oil well drilling, of platinum-rhenium and of rare earth as catalysts, of hydrogen, lead, and bromine as process additives in gasoline production, and of cobalt

in superalloys for oil refinery process equipment — all constitute large uses of these elements in conversion of energy raw materials to useful fuels. Similarly, large fractions of hafnium, zirconium, and beryllium consumption are in nuclear reactors. With regard to energy uses, lead is important for storage batteries, cobalt for magnets and jet engines, and at least half the commodities in Fig. 3 for various electronic and/or electrical applications. In addition, a large fraction of platinum consumption is for automotive exhaust pollution control.

The percentages shown in Fig. 3 are, in many cases, understated when secondary energy uses are considered. For example, about 25% of fluorspar use is in aluminum production. Since 10% of aluminum output is used as electrical conductors, about 3% of fluorspar consumption is indirectly involved in electricity transmission.

Several important problems, to be discussed later at greater length, are covered in the notes in Fig. 3. First, at least six of the commodities are obtained only as by-products of other materials. Second, nearly all of the supply of several elements are imported. In the case of tantalum, supply is relatively secure because neighboring Canada is the main producer, but for cobalt, where Zaire is the principal source, supply is in much greater potential jeopardy. A correlary of the imports problem is that for some of the elements in Fig. 3 we have both large imports and large, though presently uneconomical resources. In the longer term, given a decade or more to develop an appropriate industry, we can become self sufficient at some higher price. In the interim, however, we remain highly import dependent, and even large stockpiles give only a temporary respite. Third, several potential substitutes are shown in the notes; for example, aluminum is a good substitute for copper in most electricity transmission applications. If the automotive industry converts to the use of electric cars in the longer term, there would be insufficient lead, and batteries would have to be developed using more plentiful materials such as iron and sulfur. This problem would be somewhat mitigated by the fact that recycle of lead batteries is a highly efficient form of recycle. Fourth, synthesis is a possibility for some minerals used solely for their physical properties, but synthesis of stable chemical elements is economically infeasible by many orders of magnitude. Synthesis of quartz crystal for oscillators is already an accomplished commercial fact, and research is in progress for synthesizing sheet mica and some other mineral commodities.

Finally, very large increases in use can be expected for a few elements in energy applications in the future. This dramatic increase in use was true for uranium, the main nuclear fuel after World War II. We may see the same demand increase for thorium if certain nuclear breeder options are successfully pursued. Another possible example would be the future role of cesium in magnetohydrodynamics and for space flights using ion propulsion in the longer term. Successful development of nuclear fusion would require large increases in lithium, lead, and tungsten demand. Deployment of solar energy satellites using gallium arsenide photovoltaic cells would greatly strain gallium resources, and to a lesser extent arsenic supplies. Each of these problem types is now discussed in greater detail.

With regard to the by-products problem (Fig. 5), some elements are obtained as a main product from some ores and as a by-product from others, but many minor elements are obtained only as by-products. Most of these by-products are obtained from copper, lead, and/or zinc ores from which they are generally recovered from waste streams such as flue dusts and anode slimes in conventional metallurgical processes. As technology changes, their recoverability may change too. For example, in-situ leaching of copper (and uranium) ores is now increasing; however, in this process by-product molybdenum, gold, selenium, and tellurium is not recovered from copper ores. It is suggested, therefore, that if industry does not voluntarily find methods to assure recovery, that government support such research by industry, or conduct research on their own if industry shows no interest.

In many resource analyses, the by-product elements are often given short shrift because their overall monetary value is too small to be economically very relevant in the overall economy. Nevertheless, as shown in Fig. 3, many of them have important industrial uses in general, and energy-related applications in particular. A cost comparison has shown that the value (at 1979 prices) of 10 nonferrous by-product elements (the precious metals excluded) consumed domestically and obtained partially or solely as by-products of copper, lead, zinc, and aluminum ores is <1% of the value of these four major nonferrous metals. This fact suggests that the establishment of a government "economic" stockpile of important by-product elements would not be inordinately expensive and would be vital in the longer term because most of these elements might otherwise be lost. The result would be quite likely that these elements would never be mined in their own right because of their very low grades. It is also important

for the government to promote recovery of both major and minor elements from industrial and other wastes both to improve recycle and to minimize the release of toxic substances to the environment.

Another long-term problem not limited to by-product elements, but of concern for about a dozen elements with limited resources, involves providing an increasing supply of trace elements for agriculture (Fig. 6); unfortunately, such use is totally dissipative with no opportunity for recycle and is entirely unamenable to use of substitutes. The problem is alien to most resource analysts because it is yet far away; however, unless agricultural technology changes drastically to assure the return of agricultural wastes and their contained trace elements to the soil (and precludes use of such wastes as fuel and/or raw materials for making fiberboard, etc.), there is no doubt but that soil will slowly become more and more deficient in trace elements and require increasing supplementary additions. Figure 6 lists the elements of concern; future requirements for agriculture will, however, vary markedly from one element to another. The percentage of each element currently imported and the domestic resource-to-demand ratio are also provided as a guide to future domestic availability. The government role in this problem is mainly to make appropriate studies for the longer term because neither the agricultural nor production industries are likely to do so in the near future.

Turning now to import problems (Fig. 7), Dr. Morgan has already reviewed the short- and intermediate-term aspects. There is little doubt but that even in the longer term we will always be dependent on imports for a few commodities such as tin where geological considerations almost certainly preclude our ever finding significant domestic resources. For a significant number of elements, however, on which we are now largely too completely import dependent, we are dependent only because foreign sources are only slightly to measurably less expensive. When the world was more placid such dependence was relatively safe, except in times of war. Now, in an increasingly politically unstable world, such dependence seems more and more ill advised; however, it is the responsibility mainly of government and multinational corporations to assess such risks and to advise domestic industry accordingly. In particular, economics no longer seems to be the sole criteria on which decisions can be based.

As noted earlier, industrial and government stockpiles can relieve import cutoffs temporarily — perhaps for at most a year or two. However, since it takes a decade or more to develop mines and to build mills and refineries and the supporting infrastructure (but less time for by-product elements), a hiatus of almost a decade can easily elapse between the time of cutoff and the time that we might become largely self sufficient. Thus it seems very imprudent not to have detailed plans in hand. In particular, with the rapid decline of detanté with the USSR and racial unrest in South Africa (the major producers of chromium, manganese, and platinum metals — all of which we are now extremely import dependent), we should become wary, especially since we would have to share greatly diminished world supplies mainly with other developed nations, most of which are our allies. The recent partial cutoff of cobalt supplies from Zaire, the major producer, when prices rose rapidly from $5 to $25 per pound, is an excellent case in point. Such rhetoric may seem unduly alarmist, but, in my opinion is not so because the consequences, added to OPEC problems, are so potentially serious.

What, we may ask, is the chance for eventually becoming self-sufficient in these four metals plus nickel, for which imports now account for ≥90% of domestic demand? A possible scenario for achieving self-sufficiency, based on the data of Fig. 8, is outlined below. First, it must be recognized that world reserves and resources for all of these metals are large because all have R/D ratios ≥77 (years). Such high ratios tend to reinforce continuing dependence on imports regardless of the fact that some major foreign producers could inadvertently or purposely cut off supplies at any time. This tendency seems, in turn, to discourage research and development designed to make us self sufficient. As shown in Fig. 8, present domestic reserves of chromium, cobalt, and manganese* are nil because, even though identified resources exist, they are not now economic and are classed only as conditional resources (or reserves). However, all five metals have had limited domestic production either now, or in the past. On the other hand, overall domestic resources are large, except for chromium. This unavailability of chromium might be remedied, also, if technology for recovering chromite from ores containing <<10% chromium were available. Figure 8 also gives the approximate minimum grade of ores from which these metals are now recovered. Except for chromium,

*Manganiferous iron ore (5 to 10% Mn) and ferruginous manganese ore (10 to 35% Mn) is currently mined domestically, but manganese ore, which is defined as containing ≥35% Mn is not.

minimum grades are <1%. Finally, ordinary ultramafic rocks are unique in that these metals (except for manganese) have considerably higher average abundances than in other types of rock.

Based on these facts plus the fact that very large, presently uneconomic sulfide ore deposits of nickel, cobalt (and copper) are known to exist in the Duluth gabbros of northeastern Minnesota, we can now outline the following scenario. In the short term, only limited production can continue or be reinstated for all of the metals either as main products or by-products. In the intermediate term, the Minnesota nickel-copper-cobalt deposits could be developed using existing technology to become the main domestic source of nickel and cobalt by 1990-1995, but almost certainly at higher than the then prevailing world prices. The Minnesota deposits might also become an important source of chromium and platinum by then but only if a great deal of new beneficiation technology development on chromite and platinum metal natural alloys and minerals would be undertaken early, and successfully concluded within a few years. In the longer term, resources of nickel, cobalt, chromium, and the platinum metals could be made near-infinite if further research and development on ultramafic rocks, in general, was successful. This would be a very significant addition to the 12 to 20 elements already in infinite supply, which are the ultimate substitutes for materials in limited supply.

Although there is no absolute assurance that such research will be successful, the potential payoff for the longer term is so great that early creation of an orderly development plan seems highly worthwhile. It is more likely that private industry will, at some point, undertake efforts to recover chromium and platinum from the Duluth gabbros than that they will do research on ultramafic rocks in general; therefore, if research in this latter area is to be done any time soon it will either require government urging and support for industry or actual government research in government laboratories. A final comment on recovering these key metals from common rock albeit in this case, ultramafic rock, is that over the very long term, society may be forced to recover at least limited amounts of other elements from common rock. At this time there is considerable scientific debate as to whether this will ever be feasible either economically, environmentally, or energywise. However, because the ultramafic rocks are

unusually enriched, on the average, in certain important elements, the proposed research would be valuable as a first test of the feasibility of the general concept of recovering essentially all elements from common rock.

The problem of making the nation self-sufficient in manganese is somewhat simpler because there is a gradual decrease in grade from presently acceptable ore at ≥35% manganese down through conventional iron ores containing <5% manganese. The problem here is in gradually improving beneficiation techniques in order to produce high-grade concentrates from slowly decreasing manganese-ore grades.

The resources of limited materials can, in many instances, be extended by substitution of more plentiful materials; use of aluminum in place of copper for electrical conduction and many other applications has already been pointed out as an example. On the other hand, certain uses such as trace elements in agriculture are not now, nor are ever likely to be, substitutable.

At present, substitution is dictated by equal performance and by economic considerations. In many cases use of adequate materials rather than best materials will suffice. Substitution possibilities are much broader than the mere replacement of an equal quantity of one material for another, however. Miniaturization, so successful in electronics, is now being applied in the automotive industry. "Functional" substitutes, such as the use of microwaves in communications, has saved vast amounts of copper wire. Changing concepts and traditions in aesthetics, such as the use of stainless steel tableware in lieu of silver and the use of iron oxide pigments in place of brilliant white titania, are also feasible.

At base, substitution is controlled by the relative abundance of resources of the various chemical elements. Development of adequate substitutes, however, is a technological problem often requiring a great deal of both basic and applied research and development in physics and chemistry.

Recycle is another way of extending resources. It must be realized, first, that materials used dissipatively are not recyclable; therefore, recycle is an option mainly for metals. Recycle must be greatly improved to be really effective for the longer term where many recycles are involved.

Government activities in substitution and recycle can be manifold. Through the use of taxes and subsidies the utilization of more limited materials can be minimized. Freight rates can be revised to aid the use of recycled materials. Various devices can be used to aid research in developing adequate substitutes both by industry and government laboratories.

My final comment is in regard to data availability. It goes without saying that good and reliable materials analyses and evaluations are highly dependent on a relatively complete and detailed data base of U.S. and world resources, reserves, production capacity, production, imports, and many other factors. In this area, both the USGS and the USBM are preeminent. However, both agencies, and the USBM in particular, are very dependent on the materials industries for much of the data that they publish. Since such data are obtained mainly on a voluntary basis, the agencies must be careful not to divulge information that the industries regard as proprietary. As a result, many of the statistical tables are scattered with Ws (for data withheld), and as the data become more and more disaggregated to state, mining district, etc., levels, the number of Ws increase markedly. In some cases various subterfuges are used to present data without violating propriety, but for some uses such data are less valuable.

Unfortunately, as shown in Fig. 9, the amount of withheld data at the national production level (and even more so at sublevels) has been increasing over the years from only a few percent of the 90 commodities reviewed in the 1940 Minerals Yearbook to over 20% of the 96 commodities reviewed in the 1976 edition. This increasing data deficit has come about largely through consolidations within the minerals industries over the past 40 years. When there were many suppliers for any commodity a half century ago, it was easy to aggregate data and avoid disclosing proprietary information; today with far fewer suppliers, and only a single supplier for a few materials, such is no longer the case. This trend is no reflection on the USBM, which is only protecting their data sources. Instead, it seems imperative, first, to determine from frequent discussions with resource and materials analysts what additional data they actually need and, second, to devise methods through legislation and other means to permit the USBM to secure desired, presently withheld information.

LONGER-TERM DOMESTIC SUPPLY PROBLEMS FOR NONRENEWABLE MATERIALS WITH SPECIAL EMPHASIS ON ENERGY-RELATED APPLICATIONS

LONGER-TERM VIEW (BEYOND YEAR 2000) CAN ONLY BE SEEN DIMLY, EVALUATED BY INTELLECTUAL "GUESSES"; TRENDS CAN BE UNDERSTOOD WITH PRESENT KNOWLEDGE.

MAJOR PURPOSE IS TO AVOID SHORT-TERM DECISION ERRORS BASED ON LONG-TERM CONSIDERATIONS.

AREAS TO BE DISCUSSED:

- COMPREHENSIVE VIEW ON MATERIALS REQUIREMENTS FOR ENERGY-RELATED ACTIVITIES
- IMPORTANCE OF MINERALS BY-PRODUCT AVAILABILITY
- IMPORTS DEPENDENCE VS DOMESTIC RESOURCES
  - STOCKPILES AND NEW INDUSTRIES DEPLOYMENT
- SUBSTITUTION AND RECYCLE
- SYNTHESIS OF MINERAL PRODUCTS
- ADEQUACY OF AVAILABLE DATA FOR RESOURCE ANALYSTS

COMPARISONS OF SHORT- VS LONG-TERM ENERGY REQUIREMENTS AND DOMESTIC SUPPLY – COPPER VS ALUMINUM

	Copper		Aluminum	
	Energy Requirements (kWh/ton)[a]			
Present Resources	1% sulfide ore	15,200	50% bauxite	63,900
Year 2000 Resources	0.3% sulfide ore	29,800	30% bauxite	72,800
Future Alternative Resources	-		High-alumina clay	78,200
			Anorthosite	86,300
			Fly ash	~80,000
Recycled Metal		850-1700		1300-2000
Recycle Energy as % for Present Ores		6-11		2-3
	Current Resources and Reserves[b]			
World R/D, years		283 (62)	Bauxite only	369 (227)
Domestic R/D, years		210 (46)		8.4 (1.7)
	Alternative Future Resources			
Anorthosite		-		Very large
High-Alumina Clay		-		Near-infinite
Power Plant Fly Ash		-		~10% of coal

[a]Based on power steam plant thermodynamic efficiency of 29.4%.
[b]Values from USBM data. USGS data give lower R/D for copper and higher R/D for aluminum.

MINERAL PRODUCTS WITH DIRECT ENERGY-RELATED (40% OR MORE) USES

Mineral or Element	% to Direct Energy Use	Energy-Related Uses	Notes
Quartz crystal	100	Oscillators (electronics)	Can be synthesized
Sheet mica	96	Capacitors, vacuum tubes	May be synthesized
Gallium	91	Light emitting diodes (LED)	By-product of Al & Zn
Barium	88	Well drilling muds	
Hafnium	83	Nuclear control rods	By-product of zirconium
Rhenium	82	Petroleum refining catalyst	By-product of CuMo ores
Beryllium	73	Electronics, nuclear moderator	
Thorium	69	Gas mantles, future nuclear	Future use in breeder reactors
Thallium	67	Mercury vapor lamp	By-product of zinc
Tantalum	66	Electrical capacitors	All imported (mainly Canada)
Platinum	66	Refining and pollution control catalyst	Nearly all imported, large domestic resources
Lead	65	Storage batteries and gasoline additive	Iron-sulfur batteries a potential substitute
Strontium	62	Color TV picture tubes	All imported, moderate domestic resources
Bromine	60	Gasoline additive	Available from seawater
Germanium	59	LED, semiconductors	By-product of zinc
Copper	58	Electrical conductor	Aluminum a good substitute
Cobalt	49	Magnets, jet engines	All imported (mainly Zaire)
Mercury	48	Electrical, including $NaOH/Cl_2$ cells	Diaphragm cells a substitute
Rare earths	45	Refining catalyst, TV tubes	
Hydrogen	43	Petroleum refining	Produced from natural gas
Scandium	40	Mercury vapor lamps	By-product of U, W, H_3PO_4

CATEGORIES OF ENERGY-ASSOCIATED USES OF NONRENEWABLE MATERIALS

TYPE OF USE	EXAMPLES
DIRECT USES	
• ENERGY RESOURCE ACQUISITION	BARITE, BENTONITE, DIAMOND FOR WELL DRILLING
• ENERGY RESOURCE CONVERSION TO USEFUL FORMS	
MATERIALS OF CONSTRUCTION	COBALT FOR SUPERALLOYS FOR REFINING EQUIPMENT
PROCESS CATALYSTS	RHENIUM, PLATINUM, RARE EARTHS FOR GASOLINE
PROCESS REAGENTS AND ADDITIVES	HYDROGEN, LEAD, BROMINE
NUCLEAR REACTORS (LWR)	ZIRCONIUM, HAFNIUM, BERYLLIUM (URANIUM)
• ENERGY APPLICATIONS	
BATTERIES	LEAD (STORAGE), CADMIUM, SILVER
MAGNETS, JET ENGINES	COBALT
ELECTRONICS AND/OR ELECTRICAL	QUARTZ CRYSTAL, MICA, GALLIUM, BERYLLIUM, THALLIUM, TANTALUM, STRONTIUM, GERMANIUM, ETC.

SECONDARY USES

- EXAMPLE – 25% OF FLUORSPAR (CaF_2) USE IS IN ALUMINUM PRODUCTION, 10% OF ALUMINUM IS AS ELECTRICAL CONDUCTORS; THUS 3% OF FLUORSPAR IS FOR ELECTRICAL CONDUCTION.

FUTURE ENERGY SYSTEMS

• NUCLEAR BREEDERS	THORIUM
• THERMONUCLEAR (FUSION)	LITHIUM, TUNGSTEN, LEAD
• SOLAR ENERGY SATTELITES	GALLIUM, ARSENIC, SILICON
• MAGNETOHYDRODYNAMICS AND ION PROPULSION	CESIUM

PROBLEMS WITH FUTURE SUPPLIES OF BY-PRODUCT ELEMENTS

- SOME ELEMENTS ARE OBTAINED AS MAIN PRODUCTS FROM SOME ORES AND BY-PRODUCTS FROM OTHERS (ANTIMONY, SILVER, GOLD, MOLYBDENUM, BISMUTH)
- OTHER ELEMENTS ARE OBTAINED ONLY AS BY-PRODUCTS (CADMIUM, GALLIUM, GERMANIUM, INDIUM, ARSENIC, RHENIUM, SELENIUM, TELLURIUM, ETC., FROM COPPER, LEAD, AND/OR ZINC)
- MANY RECOVERED FROM PROCESS WASTE STREAMS – FLUE DUSTS, ANODE SLIMES, ETC.
- NEW TECHNOLOGY MAY AFFECT BY-PRODUCT RECOVERY – MOLYBDENUM, GOLD, SELENIUM, AND TELLURIUM LOST IN IN-SITU LEACHING OF COPPER ORES
- MANY RESOURCE ANALYSES NEGLECT BY-PRODUCT ELEMENTS BECAUSE THEIR VALUE IS TOO SMALL TO BE VERY RELEVANT IN NATIONAL ECONOMY; THEY ARE IMPORTANT TECHNOLOGICALLY
- BY-PRODUCT VALUE (PRECIOUS ELEMENTS EXCLUDED) LESS THAN 1% VALUE OF COPPER, LEAD, AND ZINC

<u>POSSIBLE GOVERNMENT ROLES</u>:

- PROMOTE AND SUPPORT RESEARCH AND DEVELOPMENT
- ESTABLISH GOVERNMENT "ECONOMIC" STOCKPILES
- PROMOTE GREATER RECOVERY FROM SOLID WASTES, TOXICITY PROBLEMS

TRACE ELEMENTS REQUIREMENTS FOR AGRICULTURE IN THE NEXT CENTURY

- MAY REPRESENT LARGE, TOTALLY DISSIPATIVE, NONSUBSTITUTABLE USES FOR A NUMBER OF ELEMENTS WITH LIMITED RESOURCES
- PROBLEM ALIEN TO RESOURCE ANALYSTS BECAUSE YET FAR AWAY

TRACE ELEMENT	% CURRENTLY IMPORTED	DOMESTIC R/D RATIO
CHROMIUM	>99	3 (0)
COPPER	18	210 (46)
COBALT	>99	73 (0)
FLUORINE	80	68 (20)
IODINE	92	NA (71)
IRON	36	197 (44)
MANGANESE	98	50 (0)
MOLYBDENUM	-47[a]	461 (87)
SELENIUM	59	222 (49)
TIN	>99	4 (1)
VANADIUM	37	1186 (14)
ZINC	66	34 (20)

[a]NET EXPORTS.

GOVERNMENT ROLE: MAKE APPROPRIATE AGRICULTURAL AND RESOURCE STUDIES

SOME IMPORTED MATERIALS HAVE LARGE DOMESTIC RESOURCES

- FOR A FEW SUCH AS TIN DOMESTIC RESOURCES ARE NIL ON LOGICAL CONSIDERATIONS
- FOR OTHERS DOMESTIC RESOURCES, THOUGH UNECONOMIC, ARE MODERATE TO LARGE
- IMPORTANCE OF SOURCE COUNTRY OR REGION:
  - TIN – ONLY 10% OF RESOURCES AND PRODUCTION IN FREE DEVELOPED NATIONS
  - NICKEL, TANTALUM, AND NIOBIUM – CANADA, VERY DEPENDABLE SOURCE
  - CHROMIUM, COBALT, PLATINUM METALS, AND MANGANESE – SOUTH AFRICA, USSR, AND ZAIRE, POTENTIALLY VERY UNDEPENDABLE SOURCE
- IS THE WORLD BECOMING MORE POLITICALLY UNSTABLE? IF SO, ECONOMICS CAN NO LONGER BE SOLE CRITERIA FOR JUDGING SUPPLY SOURCES.

A SCENARIO FOR CHROMIUM, NICKEL, COBALT, PLATINUM METALS, AND MANGANESE

Element	Percent Currently Imported	World Reserve Demand Ratio	World Resource Demand Ratio	Domestic Reserve Demand Ratio	Domestic Resource Demand Ratio	Production Capacity, % U.S. Demand	Minimum Grade Now Mined (%)	Grade in Duluth Gabbro (%)	Grade in Ultramafic Rock (%)
Cr	>99	208	534	0	3	>0	10-15	NA	0.3
Ni	94	77	159	<1	72	6.5	∿0.6	0.21	0.2
Co	>99	80	132	0	73	>0	∿0.06	0.02	0.01
Pt	>99	113	∿300	NA	134	0.8	<1 oz/ton	NA	<0.02 ppm
Mn	98	194	356	0	50	2.4	∿35	-	-

- In short term we remain import dependent except for industrial and government stockpiles.
- Despite large resources, 10 to 15 years required to build up industries
- Therefore, ∿10-year hiatus before self-sufficiency possible

Research Priorities:

- Develop beneficiation technology for very low-grade chromite (≤1% Cr) and platinum recovery
- Iron out problems for use of Duluth gabbros as nickel-copper-cobalt resource; continue research on beneficiation for chromium and platinum recovery
- Extend research to ultramafic rocks in general as Cr, Ni, Co, Pt resource; such research schedule, if successful, would make these metals in near-infinite supply
- Domestic manganese resources, though large, are low-grade, minimal quality; new beneficiation technology needed

WITHHOLDING OF PROPRIETARY DOMESTIC PRODUCTION DATA HAS BEEN INCREASING IN POST-WORLD WAR II ERA

Element or Mineral	Year Data Withheld (W)																																
	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79
Diatomite[a]	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
Bismuth	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
Iodine	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
Kyanite	W	W			W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
Indium				W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
Thallium				W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
Rare earths				W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
Thorium				W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
Gallium								W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
Graphite									W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
Lithium minerals										W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
Zircon														W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
Arsenic		Only limited data available													W	WW	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
Cobalt		on minor metals and non-													W	W	W	W	W	W	W	W	W	W	W	W	-	No	dom.		prod.		-	-
Tin		metals[b] in early years														W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
Beryllium													Full data						W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
Magnesite													available on						W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
Titanium metal													domestic produc-						W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
Rutile													tion (or sale							W	W	W	W	-	-	-	W			W	W	W	W	-
Magnesium metal													and/or use)																W	W	W	W	W	W
Chromium																														-	W	-	-	-
Tellurium																															W	W	W	W
Rhenium																																	W	W
Fluorspar (CaF_2)																																		W
Trona (Na_2CO_3)																																		W

[a]Data available by 3-year increments.

[b]In 1948, data also withheld on these minor commodities: oilstones, alpite, some gemstones.