CHAPTER 3

Critical Materials Consumption: Current Patterns and Trends

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CHAPTER 3

Critical Materials Consumption: Current Patterns and Trends

The metals that form the principal subject of this report—chromium, cobalt, manganese, and the platinum group—serve throughout the economy in applications that range from the essential, such as structural applications in high-performance aircraft, to the decorative, as in trim and jewelry, These metals are strategic because they are necessary in a number of essential industrial and defense applications and because the major sources of supply are considered to be vulnerable to disruption, This chapter identifies the major essential uses of these metals, describes the properties that make them irreplaceable at present, and discusses the trends in their use.

As discussed in chapter 2, the strategic nature of these materials is not static. In time, alternatives may be found to replace the metals in essential functions, or changing conditions may mean that the functions are no longer essential, It is also possible that changes in technology will cause these metals, or other materials, to increase in importance beyond their current status, Such changes are slow in coming, however, and are likely to take a number of years before they have a major effect,

Table 3-1 shows the distribution of consumption of the four metals over the major industrial sectors in the United States.

The transportation sector consists of the aviation, automotive, railroad, and maritime industries, These industries together account for 19 to 41 percent of the consumption of each of the four strategic metals,

The construction sector includes facilities for the production and processing of fuels; production of electricity; equipment for metallurgical, chemical, and food processing; and structural materials in buildings.

Examples of the uses of the strategic materials in the machinery sector are tools for metal cutting and forming, drill bits, ball and roller bearings, and other machinery components.

Important equipment in the electrical sector includes transformers, switchgear, motors, instruments, batteries, generators, cooling equipment, and household appliances. Major applications for strategic metals are in magnets, contacts and electrodes, shafts and bearings for rotating machinery, tubing and conduits, and decorative trim.

Refractory uses of strategic metals and minerals are those in which the materials must operate in an extremely high-temperature environment without chemical change or loss of desirable properties. An example is liners for boilers and furnaces. Materials for the production of ceramics and glasses are also in this category.

Chemical uses of chromium, cobalt, manganese, and platinum group metals are quite varied. They include dyes and pigments, preservatives, food additives, and catalysts for the production of other chemicals.

The listing in table 3-1 provides only *a starting* point for the analysis. Further detail on the uses of the metals is provided below.

Table 3-1.—Strategic Metal Consumption by Industrial Sector, 1980

	Chromium		Cobalt		Manganese		Platinum group	
Sector	1,000 tons	(Percent)	1,000 lb	(Percent)	1,000 tons	(Percent)	1,000 tr 02	(Percent)
Transportation	112	(19)	7015	(41)	215	(21)	731	(33)
Construction	123	(21)	0	(0)	375	(36)	171	(8)
Machinery	98	(17)	3081	(18)	165	(16)	0	(0)
Electrical	52	(9)	2530	(15)	67	(7)	526	(24)
Refractory	44	(7)	538	(3)	o	(0)	63	(3)
Chemical	87	(15)	3785	(22)	50	(5)	284	(13)
Other	71	(12)	190	(1)	157	(15)	431	(20)
Total	587	(loo)	17,139	(loo)	1,029	(loo)	2,206	(loo)

SOURCE US Bureau of Mines, Mineral Commodity Profiles, 1983

Chromium

Chromium is the most versatile of the many alloying agents used in steel. It may be added to provide high-temperature strength, low-temperature toughness, hardness, corrosion resistance, or oxidation resistance, It is also a major constituent of nickel- and cobalt-based superalloy. Additionally, in the form of chromite, it lines crucibles for molten steel and is used in forms for ferrous castings. In the form of sodium bichromate, it is processed into a variety of chemicals.

Transportation Applications

Automotive Applications

The automotive industry is one of the largest consumers of chromium. Chromium consumption by the industry is on the order of 40,000 tons per year, mainly in the form of stainless steel. Of the 5.5 pounds of chromium contained in a typical 1980 car, the National Materials Advisory Board estimated that 2.5 pounds were used for functional purposes, including suspension, chassis, and engine components and the catalytic converter (table 3-2), Further reduction of chromium usage could be achieved through attention to the exhaust emission system, particularly through the use of stainless steel-clad carbon steel in place of the solid stainless steel now in use in the converter.

Parts of the automobile engine subject to high wear, high temperature, or corrosive environments are candidates for chromium-bearing alloys. Examples include exhaust valves, which may contain as much as 21 percent chromium, and camshafts, which range from 0.9 to 1,5 percent chromium. Engine components account for slightly less than 1 pound of chromium in an "average" automobile, Of this amount, only about one-third of a pound is essential, but there is little incentive to make the reductions under the present conditions of availability and price. Further, some of the reductions, such as the use of stainless steel containing 12 to 14

Table 3-2.—Chromium Usage in U.S.-Built Passenger Cars, 1980

	Total	Essential
Propulsion:		
Cylinder block, camshafts, valves	0.860	0.325
Cooling system, electrical system	0.016	0
Carburetors, air intake, exhaust	0.079	0
Catalytic converter	2.070	2.070
Drive train	0.155	0.067 (misc.)
Subtotal	3.180	2.462
Chassis:		
Wheel covers	0.971	0
Suspension	0.261	0
Brakes	0.032	0
Steering	0,013	0
Miscellaneous	0.093	0
Subtotal	1.389	0
Body:		
Windshield wipers	0.265	0
Seat belts	0.355	0
Roof and door moldings	0.032	0
Plating	0.041	0
Subtotal	0.903	0
Total	5.472	2.462

SOURCE: As projected by the National Materials Advisory Board in 1978 percent chromium in place of the 21 percent chromium alloy now in use could not be made without additional testing to ensure that the material would behave as expected when in service.

The principal structural use of chromium alloys in automobiles is in the AISI 5160 steel used for springs in the suspension. A relatively new, but growing, use is in the main structural members of the chassis where high-strength, low-alloy steels that contain about 1 percent chromium are gaining acceptance.

In 1982, General Motors (GM) introduced a fiber composite leaf spring into the rear suspension of the Chevrolet Corvette. In 1983, similar springs were introduced into other lightweight cars in the GM line,

Unlike the case with engine parts, there is a strong incentive to reduce the use of conventional steels in the structural parts of cars, That incentive is weight reduction, which results in reduced power requirements and lower fuel consumption. However, the development of the high-strength, low-alloy (HSLA) steels has provided an alternative to other lightweight materials such as aluminum and fiber composites. These steels, which obtain their strength through the use of small additions of chromium, manganese, molybdenum, and other metals, combine high strength and low weight with conventional metal-forming techniques. The overall economics of HSLA steels have led, and are expected to continue to lead, to increasing use of these alloys in automobiles, Although these steels are not essential to the design of cars, once incorporated into a design, any replacement of materials—e.g., in response to a reduction in the supply of chromium—will be difficult to make.

Aviation

Aviation, with its demands for high strength, low weight, and oxidation- and corrosion-resistant materials with long fatigue lives and resistance to high temperature, is another major consumer of chromium. Chromium consumption by the aviation industry accounted for 3,250 short tons in 1978, of which approximately 80 percent was used in jet engines as a constituent of superalloy and of other heat-, corrosion-, and oxidation-resistant alloys. Chromium-containing steels are used in other high-temperature components of jet engines, where the exceptional heat resistance of superalloy is not required.

Superalloy, containing substantial amounts of chromium, nickel, and, in some cases, cobalt, have exceptional resistance to high temperatures. These alloys retain their strength at high temperature and stress, whereas alloy steels would fail owing to creep (a gradual deformation of a material when it is subjected to stress at high temperature) or to rapid corrosion by the hot exhaust gases of a jet engine. These materials are essential in the current designs of aircraft gas turbine engines as well as many land- and sea-based gas turbine engines.

The manufacture of superalloys accounts for a majority of the total domestic consumption of chromium metal. In 1981, consumption of metallic chromium in superalloy was 2,500 short tons or 64 percent of the total domestic consumption of chromium metal. Ferrochrome is also used in the production of superalloy, in 1981, 4,300 tons of chromium contained in ferrochrome were used in superalloy production,

Already, hundreds of superalloys are used in aircraft engines, with more being developed all the time. Some of these alloys are in widespread use, while others have become obsolete or have been superseded by newer alloys. Table 3-3 identifies some of the typical alloys used in the most severe applications in the jet engine, With regard to the metals under examination, the table shows a range of chromium (Cr) content, from a low of 8 percent to a high of almost 26 percent, and a range of cobalt (Co) content from zero to 56 percent.

Substitution of known alternative alloys is a simple method of reducing critical metal consumption in times of a shortage of raw materials. During the disturbances in Zaire in 1978-79, the cobalt-free alloy IN-718 was used as a direct substitute for Waspaloy (13.5 percent cobalt). The alloy IN-718 may be used in place

Table 3-3.—Typical Structural Alloys Used for Hot-Section Components of the Aircraft Gas Turbine Engine

Alloy	Composition (percent by weight) Ni	Co	Cr	Fe
Combustor liner:				
Hastelloy X	48	1.5	22	18,5
HA-188	22	41	22	—
Turbine vane:				
MA-754	***78***	***—***	***20***	1
MAR-M200	60	10	9	—
MAR-M247	60	10	8	–
MAR-M509	10	55	23.5	–
X-40	10.5	56	25.5	–
IN-713	72,5	—	13.5	—
Rene-77	55	15	15	—
Turbine blade:				
Alloy 454	***62.5***	***5***	10	—
MAR-M200	60	10	9	–
MAR-M247	60	10	8	—
B-1900	65	10	8	—
Rene-80	60.5	9.5	14	—
IN-713LC	72.3	—	12	—
Rene-77	55	15	15	—
Turbine disc:				
IN-100	56	18.5	12.5	—
MERL-76	54.1	18.5	12.4	–
Astroloy	55.5	17	15	—
Waspaloy	58	13.5	19.5	—
Rene-95	61.3	9	14	—
IN-718	53	—	19	18
IN-901	45	—	12.5	34
A-286	25,5	—	15	55
Case:				
Waspaloy	58	13.5	19.5	—
IN-718	53	—	19	18
IN-901	45	—	12.5	34
A-286	25.5	–	15	55

SOURCE Office of Technology Assessment

of other alloys, such as MAR-M200 (10 percent cobalt) in turbine vane and blade applications. Savings of chromium are more difficult to achieve through substitution than savings of cobalt. Chromium contents of most superalloys are in the range of 8 to 22 percent, and those lowest in chromium contain 10 percent cobalt. The substitution of IN-718 (19 percent chromium) for MAR-M200 (9 percent chromium) offset cobalt savings by increased chromium consumption.

A substitution of cobalt-free IN-713 for alloy X-40 (56 percent cobalt) in the turbine vanes of the JT- 9 engine used for wide-body commercial aircraft also occurred as a result of the cobait price increases that followed the Zairian disturbances. This substitution also resulted in a 47-percent savings in chromium consumption, although that was not the object of the substitution. Normally X-40, with its longer service life, would be the preferred alloy, but at the higher cost and uncertain supply of cobalt, the substitution was justified.

The potential to reduce critical metal consumption in the near term is limited. Chromium is an essential component of all superalloy, and most of the easy substitutions for cobalt have been identified as a result of the price increases that followed the Zairian disturbances. Opportunities for further substitutions are known (and will be discussed in ch. 7), but the time required to complete the qualification and certification process for use in aircraft engines precludes their use as a short-term response to shortages.

It is clear that chromium will remain essential in superalloy for the aircraft gas turbine engine. predicting future material needs cannot be done with confidence because of inherent inaccuracies resulting from factors that vary from the general state of the national economy to advances in engine design and materials processing, However, some sense of future material requirements is obtained by evaluating alternative scenarios for the growth of the U.S. aviation industry. Thus, it is estimated that in 1995 the United States will consume for the production of superalloy 3,700 tons of chromium metal and 6,500 tons of chromium in low-carbon ferrochrome for an increase of 50 percent over 1981. Similar estimates for superalloy production for the year 2010, based on current technology and trends, are 6,800 tons of chromium metal and 11,600 tons of chromium in ferrochrome, an increase by a factor of 2.7 over 1981 demand,

Other Transportation Applications

Other uses of strategic metals in the transportation sector include heat-resistant chromium steels in gas turbines, in steam generators and turbines for railroad and maritime applications, and in stainless steel containers for transportation of dairy products and corrosive materials.

Construction Applications

Almost 20 percent of U.S. chromium consumption is accounted for in the construction sector, with the most essential applications being in the corrosive environments associated with oil and gas production and refining and the high-temperature environment of energy production facilities. Chemical processing facilities also constitute essential uses of chromium in the construction sector.

Energy Production Facilities for Fossil Fuels

The annual chromium requirements for the construction of energy-related facilities, including oil and gas wells, coal mines, electricity generating plants, and other energy facilities were estimated in a 1979 report to the Department of Commerce. Reported consumption of chromium in 1977 by the energy industry was 20,400 short tons. When taken with the scrap generated during processing and fabrication of energy-related equipment, this sector alone accounts for 3 to 5 percent of U.S. chromium consumption. Similar estimates were made for chromium usage in a 1978 study by the National Materials Advisory Board (NMAB). These estimates are reported in table 3-4.

In its 1978 study, the NMAB estimated that 90 percent of the chromium consumption of the energy sector should be considered essential. Of the consumption in 2000, approximately 60 percent will be for stainless steel, with another 25 percent being for alloy steels. The remainder will be used in a variety of applications, including superalloy, plating, and nonferrous alloys.

Table 3-4.—Estimated Requirements for Chromium for Energy-Related Facilities, 1977-2000 (thousand short tons)

	Department of Commerce	NMAB low	NMAB high
1977	20.4	—	—
1985	24.7	—	—
1990	27.3	—	—
2000	33.2	—	—
Average	**27.2**	**19.5**	**33.7**

SOURCES U S Department of Commerce, 1979 National Materials Advisory Board 1978

Chemical and Process Applications

Production facilities of the chemical and process industries, manufacturers of acids, organic compounds, alkalies, and other corrosive materials, are major consumers of chromium, principally in the form of stainless steel. These steels are used because they combine strength with exceptional resistance to corrosion and oxidation. They are also used in applications where it is essential to prevent contamination of products by the process equipment.

The bulk of chromium consumption in chemical and process applications is accounted for by a few popular alloys: the wrought alloys; AISI types 304, 316, and 430; and the cast alloys, ACI types CF-8, CF-8M, and CN-7M. All of these steels contain approximately 18 percent chromium. In many cases, it appears possible to develop substitute steels with chromium content as low as 12 to 14 percent, although users would have to accept a lower resistance to corrosion unless additions of molybdenum were made to counteract the effects of chromium reduction, This class of steel, however, is not currently available, and several years of effort will be required before such steel could be ready for widespread use. Even if such substitutions were made throughout the industry, however, no more than one-third of the chromium consumption in this sector would be saved. Substitution by surface-treated materials, including coated, clad, and plated steels, could also be used in some applications, but limitations of cost, abrasion resistance, and corrosion resistance at welds and other joints restrict the opportunities to use these materials in the chemical and process industries.

Machinery Applications

Machinery applications of chromium include tool steels, spring steels, and alloy steels for gears, shafts, and bearings, Chromium is used largely for its contribution to *hardness* and wear resistance. The chromium content ranges from as low as *0.5* percent in some steels used for gears and bearings to as high as *12* percent in some tool steels.

Opportunities for reduction of chromium consumption in machinery applications include the use of sintered carbides in place of tool steels and alternative alloys containing manganese and molybdenum for the manufacture of gears, shafts, and bearings. Barriers to the use of these substitutes are economic rather than technical; in particular the high cost of sintered carbides relative to tool steels suggests that this would be an unlikely area of substitution except in extreme emergency.

Chromite Refractories

Chromium, in the form of chromite, is used in refractory applications such as liners for steam generator fireboxes and ladles for molten steel because of its ability to provide thermal insulation, resist stresses resulting from sudden changes of temperature, and remain chemically inert in metallurgical applications. The chromite used in refractories differs from that used as a raw material for the production of ferrochrome because of its higher aluminum content. While the high aluminum content makes chromite undesirable for ferrochrome production, it improves the refractory characteristics. Chromite sand is also used in molds for ferrous castings.

Refractories account for about 7 percent of U.S. chromium demand. Current data are not available but perhaps as much as 19,000 tons of chromium were lost in spent, unrecycled refractory bricks in 1974; additional chromite is contained in accumulated refractory waste-piles around steel mills, copper smelters, and other refractory-using facilities,

Steelmaking continues to account for most use of chromite-containing refractories, although its consumption has declined precipitously since 1965. Phase-out of open hearth steelmaking with basic oxygen furnaces that use virtually no chromite refractories is the primary cause. This decline was moderated, and partially offset, in the early 1970s by using chromite-containing refractories in electric steelmaking furnaces and in argon-oxygen-decarburization (AOD) vessels for stainless steel production. However, since the mid-1970s, chromite refractories have been replaced rapidly by water-cooled panels in electric furnaces. In addition, dolomite, which is readily available domestically, now accounts for about two-thirds of the refractory material used in AOD vessels, according to the major U.S. producer.

Electrical and Chemical Uses

In the electrical sector, chromium is used in shafts, bearings, and other applications requiring wear resistance and in decorative applications, Requirements for chromium are similar to those of the machinery sector.

Chemical applications accounted for 15 percent of total U.S. chromium consumption in 1980, principally in pigments, metal treatments, and leather tanning, Based on data compiled in 1976, the National Materials Advisory Board estimated 40 percent of the chromium use in chemical applications to be essential.

Cobalt

In contrast to the breadth of applications for chromium, uses of cobalt are limited. This is due, in part, to the availability of alternative metals that provide similar properties at lower cost, The current uses of cobalt are, therefore, those in which substitutions are difficult to achieve. The principal uses of cobalt are in superalloy (for the beneficial properties cobalt imparts at high temperatures), magnets, cemented carbides, and catalysts in petroleum refineries. Other uses include tool and alloy steels, and salts, driers, and other chemicals, In 1982, the NMAB surveyed the uses and made estimates as to the essential needs of cobalt, in comparison to actual consumption. The results of these estimates are reported in table 3-5. The overall estimate of the NMAB was that 50 percent of the cobalt now consumed is essential, with over 58 percent of the essential consumption being accounted for in superalloy and another 14 percent of the essential uses going into cemented carbides.

Transportation Applications

The aviation industry accounts for the majority of cobalt consumption in the transportation sector. As shown in table 3-3, cobalt is an important constituent in many alloys in the jet engine. Superalloy may contain anywhere from no cobalt to 65 percent cobalt. The selection of a particular alloy is based on a range of properties, including yield strength, creep resistance, oxidation resistance, formability, and cost,

The beneficial properties that cobalt can impart to superalloys and its availability at reasonable prices (until the market disruptions of 1978-80) led to the current level of use of cobalt. The F-100 engine, used in F-15 and F-16 aircrafts, contains approximately 150 pounds of cobalt. The JT9D commercial aircraft engine contains approximately 165 pounds.

New engines may be designed to use cobalt-free alloys. The new General Electric F101 and F404 engines use Inconel MA 754, a mechanically alloyed, cobalt-free alloy, for the turbine vanes.

Superalloy accounted for 6.3 million pounds or 41 percent of the 1980 reported domestic cobalt consumption. Under current trends, it is anticipated that 8.3 million pounds of cobalt will be used in the production of superalloy in 1995 (for all applications, not the aircraft engine alone), and 12.9 million pounds of cobalt will be required for these uses in 2010.

Cobalt use in other parts of the transportation sector is small. Applications include hardfacing alloys used on the surface of exhaust valves in automobile engines.

Machinery Applications

Cobalt use in the machinery sector includes drill and cutting bits made for high-speed and high-temperature applications, surface coatings for hardness and wear resistance, and high-strength steels for rocket motor casings, and dies and structural uses in large machinery. These applications are met primarily through the use of three materials: cemented carbides, tool steels, and maraging steels.

Cemented Carbides

Cutting tools used for machining of steel and cast iron, mining and drilling bits, small- and medium-sized dies, cutoff tools, and screw-machine tools, all of which require qualities of abrasion resistance, hardness, impact resistance, and heat resistance, depend on cemented carbides for their demanding properties. Cemented carbide tools may account for as much as 75 percent of the metal removed in domestic metal-cutting operations and for over 50

Table 3-5.—Uses of Cobalt, 1980 (thousands of pounds)

Category	Reported consumption	Essential consumption	Essential fraction
Superalloys	6,300	4,500	71%
Magnets	2,300	400	17
Cemented carbides	1,300	1,100	85
Hardfacing	600	300	50
Steel	400	200	50
Other metallurgical	400	200	50
Catalysts	1,700	100	6
Salts, driers, and other chemicals	2,200	200	41
Total	15,300	7,700	50%

SOURCE National Materials Advisory Board, *Cobalt Conservation Through Technological Alternatives*, NMAB-406, p 2 percent of the cutting and crushing functions in mining, oil and gas drilling, and construction activities.

Cemented carbides are formed from a mixture of tungsten carbide powder, which provides the hardness and wear resistance, and cobalt powder, which acts as the cement that holds the carbide particles together. The cobalt, carbon, and tungsten produce a synergistic effect that allows relatively easy production by sintering (heating the powder shape) to the point where the surface of the cobalt powder melts, dissolving some of the tungsten carbide to form an exceptionally strong bond,

Materials other than cobalt, notably iron and nickel, with some chromium when needed for corrosion resistance, have been used with some success as substitutes for the cobalt binder, but only with some sacrifice in performance. Since the applications of cemented carbides are in uses essential to the economy, and since there are no satisfactory substitutes for either the carbide tools or for the cobalt used in the binder, the use of cobalt in this application must be considered to be critical to the United States.

Tool Steels

Tool steels are used in a variety of metal cutting and forming applications, but it is only in the high-speed, high-temperature applications that cobalt-containing tool steel is of particular importance. These steels are classed as M-type and T-type. Past consumption of cobalt in these classes of tool steels is summarized in table 3-6,

Table 3-6.—Cobalt Consumption in Tool Steels (short tons)

	1979	1980	1981
Domestic production:			
M-Type	2,905	2,941	2,344
T-Type	639	552	479
Subtotal	3,544	3,493	2,820
Imports	815	559	1,042
Total	4,359	‘4,052	3,892
Approximate cobalt content (8°/0 average)	349	324	311

SOURCE Off Ice of Technology Assessment, based on data in National Materials Advisory Board, *Cobalt Conservation Through Technological Alternatives,* NMAB 406, p 107

Cobalt-containing tool steels have been a target for substitution research, which has produced alternative alloys with little or no cobalt through the use of powder metallurgy. For example, a new alloy, CPM Rex 20, is a replacement for the high-speed tool steel M42, and CPM Rex 25 may replace alloy T15.

Cobalt-based, hardfacing alloys have been used as wear-resistant materials for over 60 years. Applications include cutters, knives, and surfaces of unlubricated bearings, Representative hardfacing alloys include Stellite 1, 6, 12, and 21, all from Cabot Co., which range from 53.5 percent to over 67 percent cobalt content. A substitute alloy containing less than 14 percent has reportedly been developed, but it is not yet in commercial use.

Maraging Steels

Maraging steels are high-strength alloys that may be heat-treated in large sections and thicknesses to increase their strength further. They run from a low of 7.5 percent to a high of 12 percent cobalt. The major maraging steels are designated as 18 Ni200, 18 Ni250, 18 Ni300, and 18 Ni350. The composition of these alloys are listed in table 3-7, The last three digits of the specification (200, 250, 300, and 350] refer to the strength level of the steel, i.e., the 18 Ni250 has a yield strength of 260,000 psi. These steels are noted for their ultrahigh strength with high toughness. The steels were developed for aerospace applications, but they are now also used in structural applications. Maraging steels achieve full strength and toughness through simple aging treatment (3 hours at 9000 F or 480° C). Hardening and strengthening do not depend on cooling rates, so properties can be developed uniformly in massive sections with almost no distortion. Exact figures on consumption of maraging steels are unavailable, but during the 1976-78 period, annual consumption was in the range of 1,000 to 2,000 tons per year of steel, requiring 180,000 to 360,000 pounds of cobalt, Of this consumption, only part is included in the machinery sector. The remainder is consumed in aviation applications and is included in the transportation sector.

Table 3-7.—Composition of Maraging Steels

	Ni	co	Mo	Ti	Al	Zr	B
18Ni200	18.5%	5 %	3.25%	0.2%	0.1%	0.01%	0.003%
18Ni250	18.5	7,5	4.8	0.4	0.1	0.01	0,003
18Ni300	18,5	9.0	4.8	0.6	0.1	0.01	0.003
18Ni350	18.5	12.0	4.8	1.4	0.1	0.01	0,003

Ni nickel
co cobalt
Mo molybdenum
T i titanium
Al = aluminum
Zr = zirconium
B -boron

SOURCE National Materials Advisory Board, *Cobalt Conservation Through Technological Alternatives*, NMAB 406, p 110

Chemicals and Catalysts

Cobalt is an essential material in catalysts for the refining of petroleum and for the production of chemicals. In 1982, about 1.5 million pounds of cobalt (down slightly from 1.7 million pounds in 1980) were used in petroleum refining and chemical production, of which all but 426,000 pounds were recycled.

In refining, cobalt-molybdenum catalysts are used to remove sulfur and heavy metals from petroleum, with molybdenum being the more active of the two metals. Substituting nickel for cobalt has proved somewhat successful, but opportunities are limited because nickel-molybdenum catalysts operate at higher temperatures and pressures than do cobalt-molybdenum catalysts. Without modification of the process equipment, the use of nickel catalysts would result in a decline in the processing efficiency and production rate of the refinery. Even accepting this drawback, cobalt cannot be entirely substituted because some reactors were not designed to operate under the more severe conditions required by nickel-containing catalysts.

Over 97 percent of the approximately 225 domestic petroleum refineries use some form of catalytic process. Hydroprocesses, which upgrade the quality of crude oil, are increasing in importance with the greater use of lower quality feedstocks. There are five important processes which are grouped as hydroprocessing: hydrotreating, hydrorefining, hydrocracking, residual hydrosulferization, and hydrogenation of pyrolysis gasoline. All use substantial quantities of cobalt-bearing catalysts. The annual consumption of cobalt in the petroleum industry is 970,000 pounds, Some cobalt is recycled, but about 340,000 pounds of high-quality cobalt are required every year for replacement of spent catalysts, principally for hydroprocessing catalysts which are not recycled. Although processes exist for recovery of cobalt, molybdenum, and other metals from spent catalysts, the majority is disposed of in landfills and dead storage while a small amount is exported.

Approximately 565,000 pounds of cobalt were used in catalysts for the production of feedstock for polyvinyl chloride and of unsaturated polyesters in 1982. Of this amount, 479,000 pounds, or 89 percent, was recovered through recycling. Generally, the particular processes have been designed around the cobalt catalyst, so substitution of alternative catalysts is not feasible. Only through the use of alternative chemical processes would it be possible to use a different catalyst.

Electrical Applications

Cobalt is used in the electrical sector because of its magnetic properties. Cobalt-containing magnets have many applications in electric motors and generators and in acoustic equipment, although a significant share of the market was lost to ferrite magnets as a result of the cobalt price increases in 1979 and 1980.

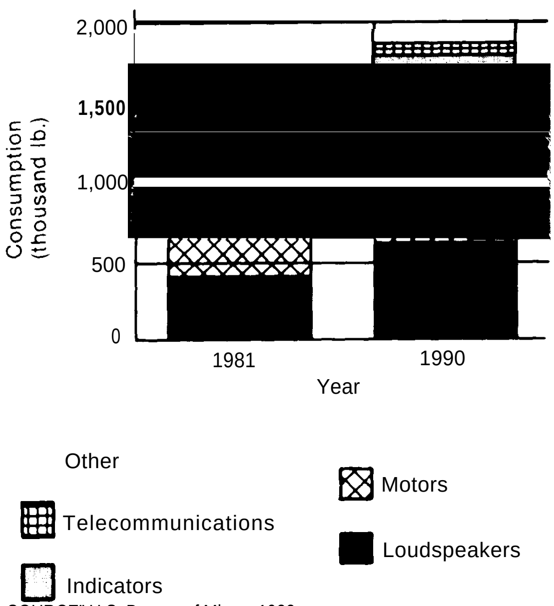
Cobalt is used in three principal types of magnets: the aluminum-nickel-cobalt (Alnico), iron-chrome-cobalt (Fe-Cr-Co), and rare earth-cobalt magnets. A fourth cobalt-containing magnet utilizes amorphous cobalt-base alloys that are rapidly cooled from a molten state to obtain a glassy, noncrystalline structure. The conventional Alnico and Fe-Cr-Co magnets account for *90* percent of the market for magnets, with the remainder being accounted for by the rare earth-cobalt magnets.

The price increases of the 1978-79 period initiated major efforts at substitution of noncobalt magnets (principally ceramic-hard ferrites) in magnetos and loudspeakers. These efforts were largely successful, to the point that even though the price of cobalt declined, the ferrite magnets retained control of their newly captured markets.

Most substitutions that could be made were made during the period of high cobalt prices, and further substitutions are unlikely, except in the event of an extremely severe shortage or major price increase.

The outlook for the future use of cobalt in magnets is for an extended period of relatively low growth, as shown in figure 3-I. The total

Figure 3-1.- Current and Projected Cobalt Consumption in Magnets, 1981.90



SOURCE" U S. Bureau of Mines, 1982

growth for the 9-year period *1981-90* is estimated at *18* percent, or an annual rate of *1.9* percent. Most striking is the precipitous decline in cobalt magnets in the telecommunications area. This decline is due to increasing miniaturization, digital signaling, and large-scale integration.

The importance of cobalt in its present applications is indicated by Bureau of Mines' estimates that a threefold increase in cobalt price would only produce a lo-percent reduction in consumption, to about *1,8* million pounds in *1990.* A much more drastic increase, a factor of 10, could cause a much more significant decrease, to approximately *400,000* pounds, which would be mostly in the loudspeaker and motor applications. This fraction *(20* percent) of the normal consumption is viewed by the NMAB as the essential requirement for cobalt in magnetic applications,

Other Cobalt Applications

There are two principal uses of cobalt in the production of refractory and ceramic products. First, cobalt is used to prepare the surface of metals for binding by ceramic layers. In this application, cobalt, in the form of cobalt oxide, is added to the glasses that are applied to the steel base. Second, cobalt oxide is used as an intense blue pigment in ceramic products and as a decolorizer to offset the effects of iron and chromium in glass.

Organic salts of cobalt, which can be manufactured from any variety of cobalt metal or oxide, are used as driers in inks, varnishes, and oil-based paints. Inorganic salts and oxides are used in pigments, animal feed, and a variety of other applications, all of which consume relatively minor amounts of cobalt.

Manganese

Over 90 percent of manganese is consumed in the production of metals, mostly by the steel industry. The remainder is used within the chemical industry and the battery industry, and for various other uses, Table 3-8 shows the distribution of consumption among the metallurgical industries.

Manganese is used by the iron and steel industry in two forms: ore and ferroalloy. Ore is generally added during the ironmaking process, while ferroalloys may be added to the ladle after crude steel has been produced.

The function of manganese in the production of steel is to improve the high-temperature characteristics of steel by replacing harmful iron sulfide by the more benign manganese sulfide. When allowed to form, iron sulfide migrates to the boundaries between grains in the steel, where it remains liquid or extremely plastic after the rest of the steel has solidified. As the hot steel is rolled into useful forms, cracking results along grain boundaries, a characteristic known as "hot shortness. " To control iron sulfide formation manganese is generally added at a ratio of 15 or 20 times the content of sulfur. In "resulfurized" steels, where sulfur is added to improve the machining properties, a minimum ratio of 7.5 parts manganese to I of sulfur may be acceptable.

Table 3-8.—U.S. Manganese Consumption,[a] 1980 (thousand short tons contained manganese)

	Ferromanganese	Manganese metal
Steel:		
Carbon steel	536	6
Full alloy steel	97	1
High-strength low-alloy steel	56	1
Stainless steel	13	2
Other steel	2	< 1
Subtotal	704	10
Non-steel:		
Cast iron	21	< 1
Nonferrous alloys	3	14
Miscellaneous	2	1
Subtotal	26	15
Total	730	25

[a]Data is based on information reported to the Bureau of Mines. Not all consumption is reported, so total reported consumption of manganese is lower than the apparent consumption reported in table 3-1.

SOURCE: George R. St. Pierre, et al., *Use of Manganese in Steelmaking and Steel Products and Trends in the Use of Manganese as an Alloying Element in Steels*, contractor report submitted to the Office of Technology Assessment, 1984, p. 97.

Manganese is also added to steel to improve the steel's strength, hardness, or toughness. Although other elements may be capable of imparting the same properties, manganese is often preferred because of its low cost and the past experience with manganese in similar uses,

One steel product with a high percentage of manganese as an alloying agent is the impact- and abrasion-resistant steel known as "hadfield" steel. This use accounts for approximately 70 percent of all high manganese steel. Total production of these steels is about 100,000 tons per year. The hadfield steels are noted for the property of work hardening where the strength of the material increases as it is used. Hadfield steels are extremely useful in applications where equipment is repeatedly subjected to high impact, such as earth-moving and excavation equipment.

Another steel with a high proportion of manganese is the 200 series of stainless steels. These steels were developed in the 1950s and 1960s in response to uncertainties over the availability of nickel. The addition of about 6 percent manganese to the 300 series of stainless steel allows the reduction of nickel content from 8 to 4 percent. The resulting steel has performance characteristics similar to the 300 series and enjoys a slight price advantage. However, compared with the widespread experience with the 300 series, satisfactory data on the performance of the 200 series in extended use is lacking, Moreover, producers have not promoted the 200 series. Thus, the use of the 200 series has been limited, and there is no expectation for any change in this pattern.

Manganese is also used in nonferrous applications. The largest of these is the 3000 series aluminums, which contain about 1.5 percent manganese. Estimated manganese consumption by the aluminum industry is between 10,000 and 15,000 tons per year, possibly growing to 20,000 by 1990. Manganese use in cast and wrought copper alloys is much less, on the order of 1,500 tons per year.

Manganese, in the form of manganese dioxide, is used in conventional carbon-zinc batteries. Manganese ore is used to produce potassium permanganate, drying agents for inks, paints, and varnishes, and as fuel additives. Manganese is also used to a small extent in fertilizers, animal feed, ceramics, and uranium processing.

Platinum Group Metals

The platinum group metals (PGMs) are noted for their stability in extreme environments. Resistant to high temperatures and to chemical attack, PGMs are used in furnaces for growing single crystals of oxide compounds, in the manufacture of glass fiber and high-quality optical glass, and in thermocouples and electrodes in electrical applications, PGMs are used as catalysts in the production of nitric acid, in the refining of petroleum, and in the treatment of exhaust gas from automobile engines. Contacts of both low- and high-voltage switches employ PGM alloys, as do integrated circuits and resistors. Other uses are in jewelry and in medical and dental applications.

The consumption of PGMs grew by a factor of 2.7 between 1950 and 1970. Consumption in the chemical industry more than doubled, petroleum refining grew to account for one-tenth of consumption, the electrical uses quadrupled, dental and medical uses doubled, and glassmaking became another important consumer. In that 20-year period, the only decline was in the jewelry and decorative sector. This was the single largest end user in 1950 accounting for 35 percent of consumption; in 1965 it accounted for only 5 percent.

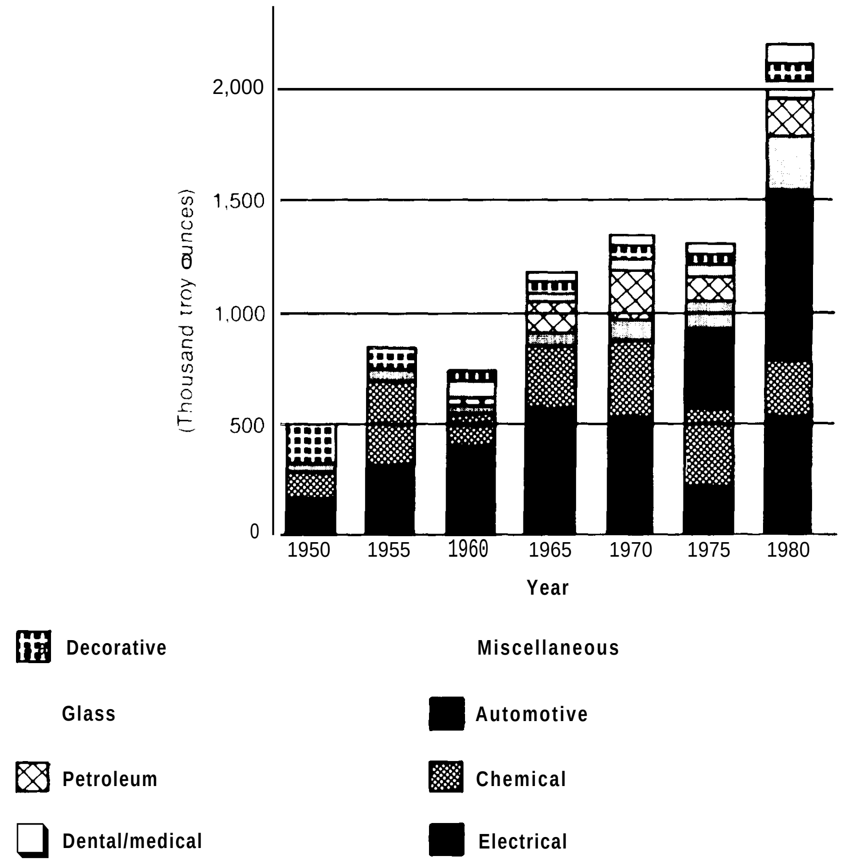
With the passage of the Clean Air Act in the 1970s (Public Law 91-604 and amendments), a new use for PGMs developed: the automobile catalytic converter, The catalytic converter was first used nationwide in 1975. Annual consumption of PGMs almost doubled within a decade. By 1980, the mix of end uses had shifted so that autos accounted for 33 percent of consumption, electrical, 24 percent; chemical, 13 percent; dental and medical, 12 percent; petroleum, 8 percent; and glass and jewelry, 3 percent each (see fig. 3-2].

Consumption patterns of PGMs differ among the metals. While the major use of platinum is in the automotive catalytic converter, the major uses of palladium are in the electrical and dental/medical sectors. The other metals are used largely in the chemical and electrical sectors.

Transportation Applications

The imposition of standards for automobile emissions resulted in the use of catalysts in automobiles, starting with the 1975 model year. As a result, the automotive industry quickly became the major consumer of platinum, the key element in the catalytic converter. In 1975, approximately 80 percent of all new cars were equipped with the converter. This converter, intended to promote the complete combustion of carbon monoxide and unburned hydrocarbons in the hot exhaust gas, averaged approximately 0,062 troy ounces of PGMs per car, of which about 70 percent was platinum and the remaining 30 percent was palladium. By 1983, virtually all new gasoline-powered cars and light trucks were equipped with catalytic converters, Tighter restrictions on the emissions, including oxides of nitrogen, lead to the development of a new three-way catalyst that uses more PGMs, including rhodium, an element not found in earlier converters. A typical con-

Figure 3-2.— Distribution of Platinum Group Metal Consumption by Applications



SOURCE U S Bureau of Mines

verter on a 1983 car contains, on the average, 0.079 troy ounces of PGMs, of which about 70 percent is platinum, 22 percent is palladium, and the remaining 8 percent is rhodium. The historical consumption of PGMs by the automotive industry is reported in table 3-9.

The future consumption of PGMs in the catalytic converter will be determined by two factors. First is the outlook for domestic production of cars and trucks. Forecasts of auto production are dependent on a number of factors, including the price of fuel, the general state of the economy, and the competitiveness of domestic producers with foreign producers. As a basis for estimating future PGM requirements, a range of forecasts, based on projections made for the Department of Energy, have been made and the baseline results are presented in figure 3-3.

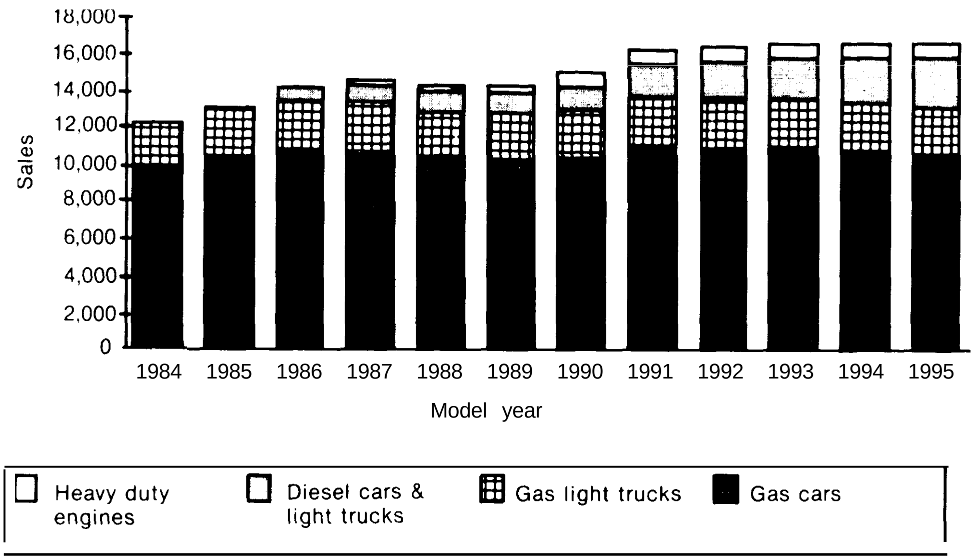
Table 3-9.—Annual Consumption of Platinum Group Metals in Domestic Automotive Catalytic Converters

Year	Sales of gasoline cars and trucks (1,000s)	PGM (1,000s of troy ounces)
1975	9,346	443
1976	11,202	502
1978	11,979	491
1979	13,255	618
1980	10,431	704
1981	9,827	722
1982	9,512	685
1983	10,715	770

SOURCE Sierra Research

The second factor to affect critical metal consumption is the design of the catalytic converter itself. Despite predictions made at the converter's introduction, neither improvements in engine design nor research into alternative catalysts have resulted in the decline in impor-

Figure 3-3.—Estimated Future Vehicle Sales in the United States



tance of the PGM-containing converter as the principal means of meeting air quality standards. This will probably continue to be the case for some time. While it appears possible to design an engine that could meet the air quality standards, it seems unlikely that any new design will soon be able to compete economically with the gasoline or diesel powerplant.

Based on the medium-growth projections for future sales of cars and trucks, and on the assumption that the catalytic converter will remain essentially unchanged, the projected annual consumption of PGMs in 1995 is estimated to be 1.4 million troy ounces. Consumption estimates for 1995 based on the high auto sales forecast are 1.7 million troy ounces of PGM, and the low forecast results in 1.1 million troy ounces of PGM. Estimated metal consumption for the period 1984-95 is shown in figure 3-4.

Construction Applications

Petroleum production accounts for approximately 9 percent of U.S. platinum consumption as measured by sales of new metal and refined scrap to industry. PGMs are used by the petroleum industry in two processes: reforming and hydrocracking. Unlike the case of cobalt catalysts, these metals are subject to tight monitoring and control, with the result that less than 10 percent of the annual consumption of these metals is lost in the petrochemical industry,

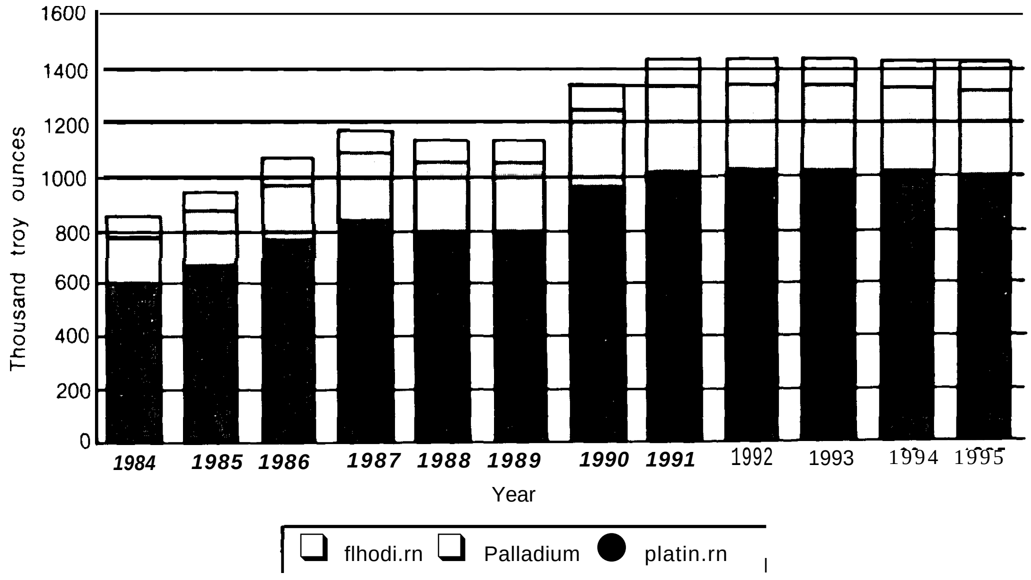
Chemical Applications

Chemical industry applications include the manufacture of nitric acid from ammonia. The PGMs contained in catalysts in these applications are largely recovered for reuse, New material is required for increases in processing capacity and to make up losses in recycling.

Electrical Applications

For many years, PGMs, particularly palladium, have been used in telephone switching systems, a use which is declining as a result of the rapid introduction of solid-state switches. In turn, the increased use of integrated circuits is resulting in increasing demand for PGMs. In integrated circuits, PGMs are used as contacts between the circuit itself and its outer package.

Figure 3-4.—Estmated PGM Requirements in Catalytic Converters for Domestic Automobile Production, 1984.95



SOURCE Sierra Research, 19&3

Electrical Contacts

An essential property of electrical contacts in mechanical switching systems is low contact resistance, or low resistance to the flow of electricity through the surfaces of the contacts. This property is greatly influenced by the condition of the surfaces. Resistivity is increased either through the wear of the surfaces or through the creation of insulating films,

If contacts are to have high reliability and long life, they must be resistant to adhesive and abrasive wear. Adhesive wear occurs where the mating surfaces adhere to one another during sliding, resulting in the transfer of metal to the opposite contact, the edge of the contact area, or to debris. Adhesive wear is determined by the material's hardness and ductility and by the strength of the adhesive bonds which form between surfaces.

Resistance to corrosion is critical in electrical contacts. Most metals form insulating polymer or oxide films on their surfaces. Generally, although not always, these films have lower conductivity than the surface metal. Even films only a few angstroms thick can cause substantial increases in contact resistance, so the selection of a surface material for contacts must consider the corrosive elements in the operating environment, the chemical products that may be formed by the contact metal, and the physical and electrical properties of those products.

Of the total consumption of PGMs in the electrical and electronics industries in *1981,* approximately **50** percent went into the production of electrical contacts, mainly in devices for opening and closing circuits in telecommunications systems. Although gold contacts generally offer superior performance, cost considerations have resulted in the use of palladium and palladium-silver alloys. As a result of the increasing use of solid-state switching by the telecommunications industry, the consumption of palladium in this application will be declining for the rest of the century.

Ceramic Capacitors

Ceramic capacitors now constitute the major market for palladium in the electronic sector. The ceramic capacitor industry alone consumed approximately 500,000 troy ounces of palladium in 1983, which is expected to have doubled to 1 million troy ounces in 1984, Unit shipments of multilayer ceramic capacitors (MLCs), the largest and fastest growing class of ceramic capacitors, are expected to grow at nearly a 20-percent annual rate through the 1980s.

Multilayer ceramic capacitors are rapidly replacing the single-layer capacitor, MLCs are built of many thin layers of ceramic material, with electrodes made of gold, silver or PGM alloys separating each of the several thin layers. The electrodes exit on alternate ends of the capacitor, so the plates act in parallel, giving a larger effective area and a higher capacitance. The manufacturer controls the final capacitance of an MLC by varying the area, the thickness of the ceramic layers, the number of layers, and the dielectric constant of the ceramic. The end result is a sturdy, highly compact capacitor.

In creating MLC conductive layers, manufacturers use a metallic ink to print electrodes on a tape of ceramic material, which is then assembled into a capacitor prior to baking or firing into the finished component. The firing temperature necessary for the typical ceramic material (alkali-earth titanates)—about 1,3500 C—is too high for silver alone to serve as the electrode material, Gold or platinum could be used but their high cost, several hundred dollars per troy ounce, leads manufacturers to use palladium or a palladium-silver alloy as the electrode material.

Driven by a need for lower costs, manufacturers have advanced MLC technology from the use of platinum electrodes in the early 1960s, to gold-platinum-palladium electrodes (which are still the most desirable, but most expensive, electrode material) in the late 1960s, to pure palladium in the 1970s, and most recently to silver-palladium, Even with this savings, however, the electrodes still account for 40 percent of the total material cost in the capacitor, In moving to the 70 percent silver alloy, manufacturers accepted some compromise in the properties of capacitors, The use of the high-silver electrodes, which have a lower melting point than the pure palladium electrodes they replace, requires a lower firing temperature to prevent oxidation of the silver during processing and to avoid reactions between the electrodes and the dielectric layers. The silver also tends to migrate into the ceramic during firing, which can lead to various electrolytic reactions, causing inconsistencies in performance and, possibly, failure of the capacitor.

With a higher melting point, nickel appears to have greater potential as a substitute material in the MLC electrode. Producers currently find nickel's properties difficult to control, but the Japanese are starting to use nickel in limited applications. The use of nickel requires expensive processing in an oxygen-free atmosphere, but the lower cost of nickel may provide incentive for further development.

A developing alternative to palladium electrodes is a lead alloy, In this process, known as the advanced Corning electrode, or ACE, the ceramic is printed with an ink made of a mixture of carbon-like powder and dielectric powder. During firing, the carbon material burns away, leaving the layers of ceramic separated by pillars of the dielectric powder, After firing, lead is injected into the voids left by the carbon powder. This process was introduced in 1983 by Corning [the sixth largest U.S. ceramic capacitor manufacturer), with encouraging results. If this process is able to produce consistently high-quality products, the lower cost of lead relative to palladium and silver will provide the driving force to encourage its widespread use.

Acceptance of new manufacturing technologies is often a long process. However, in the MLC industry, which is pressured by Japanese competition and by a growing demand for palladium that is certain to force prices upward, new processes may be accepted as quickly as they can be shown to provide the essential high reliability with reduced materials cost. Although the growing consumption of palladium in ceramic capacitors will continue for the next several years, technical advances spurred on by limited supplies of this metal are likely to provide lower cost alternatives that will eventually be accepted by the electronics industry, resulting in a slow, but long-term decline in palladium consumption in this sector.

Refractory Applications

PGMs are used as crucibles in the production of single crystals of certain oxide compounds that can only be manufactured at extremely high temperature, The high-temperature resistance, combined with the chemical stability, allows the production of crystals without danger of contamination by the crucible and tools used in the growth process.

PGMs are also used in the melting tanks, stirrers, and crucibles for melting high-quality glass and as dies and forming devices for glass fiber.

As with the catalytic uses of PGMs, the refractory and glass applications are largely recovered for reuse.

Other Applications

A variety of chemical compounds are used in cancer chemotherapy. In addition, PGMs are used in dental applications in dental crowns and bridges. These are all considered unrecoverable applications of PGMs.

Use of PGMs in jewelry has been relatively limited in the United States, but it is quite popular in Japan. Platinum alloys make good jewelry material, but they are easily replaced by gold.

Future Applications for Strategic Materials

Nonconventional Energy Systems

In recognition of the limited domestic reserves of petroleum and the limitations on the uses of coal in its natural form, the United States has devoted considerable effort to technological approaches to make efficient use of its energy resources and facilities. Some of this work has resulted in new energy systems that may have significant effect on U.S. needs for strategic materials. Several of the technologies that may have major requirements for strategic materials (particularly the PGMs) are discussed below.

Large-Scale Fuel Cell Stations

In order to make most efficient use of electrical generating capacity, a number of power storage systems have been examined. In one system now in use, electricity generated in off-peak hours moves water above a hydroelectric plant, allowing additional generation during peak hours without the need for expensive additional capacity. Another system being considered for the future is based on the fuel cell. The fuel cell is an electrochemical device that directly converts chemical energy into electric power, It can also reverse the process, converting electrical energy into chemical energy, storing it, and then converting it back into electricity when needed.

An example of current fuel cell technology is the phosphoric acid cell, In this system, hydrogen, which is obtained from methane or naphtha, is reacted with oxygen from the atmosphere to produce electricity and water. The phosphoric acid, which serves as the electrolyte in the cell, is kept at about 350° F. In order for the reaction to proceed, a platinum catalyst is necessary. Demonstration models of the fuel cell now require approximately 6.3 grams of platinum per kilowatt (kW) of power output. At a production level of 750 to 1,000 megawatts (MW) per year, as suggested by one developer as a target for 1995—in 2000, the annual platinum requirement of fuel cells could be as high as 6.3 metric tons (tonnes). This would be reduced to 1.9 tonnes per *year if* developers reach their target for reduced platinum loading of 1.9 grams per kW. The need for platinum may be eliminated if current research leads to development of alternative catalysts or alternative fuel cell designs that do not require platinum catalysts.

Synthetic Fuels

Currently, there is little synthetic fuel production from coal, oil shale, or biomass. Over the next 25 years, production of synfuels is expected to increase. Cobalt and PGMs will play a role in the development and growth of these energy sources,

Liquid and gaseous fuels from coal are expected to be the first large-scale synthetic fuels. Two processes for liquefaction of coal are known: direct and indirect. In the direct process, coal is hydrogenated to form a liquid in the presence of a catalyst, usually containing iron, although one process, the H-Coal process, uses a cobalt-containing catalyst. In any case, the liquid products obtained from coal and from oil shale will require substantial hydroprocessing of a type similar to that used with petroleum.

In the indirect process, coal is reacted with steam and oxygen to produce syngas, a mixture of carbon monoxide and hydrogen gas. The syngas is converted catalytically to methane (using a nickel catalyst) or to gasoline (using an iron or a cobalt-containing catalyst).

Critical Metals in Automobiles

The automobile of the future will certainly differ from those of today. With the large capital investment required to manufacture the millions of automobiles sold every year, it can be assumed that changes in design will not be radical, but even gradual changes may have significant effects on the consumption of strategic metals. One example is dual-fuel vehicles. These vehicles use a mixture of gasoline and methanol (from 3 percent up to 10 percent methanol). The methanol content requires a more corrosion-resistant material for the fuel tank, fuel line, and carburation system than is now used in automobiles. Stainless steel now offers the best performance characteristics for much of the fuel system when a gasoline/methanol mixture is used. However, auto manufacturers hope to develop alternative materials that will have lower raw material and fabrication costs.

Summary: Essential Uses of Strategic Metals

Attempts to predict future requirements for materials are fraught with difficulties, owing both to the uncertain growth of industrial and consumer needs and to unforeseen changes in manufacturing technology. Discussions of future essential requirements for specific materials are even more difficult since essentiality is not a simple yes-or-no characteristic. The need for a material in a particular application depends on the cost and performance of alternative materials and on the time available to replace the material, to redesign the component in which the material is used, or even to eliminate the need for the application altogether.

Despite the difficulties, however, it is necessary to estimate future materials requirements and to identify the applications in which chromium, cobalt, manganese, and PGMs are most essential. As a starting point, it is helpful to consider extrapolations of current materials requirements. The U.S. Bureau of Mines has made statistical projections of future materials requirements based on current patterns and trends; these are presented in table 3-Io.

While these projections are useful as a starting point, there are a number of important modifications and clarifications that arise from a detailed study of the major uses of strategic metals. The major points are as follows:

- Chromium consumption for most applications, other than chemical and refractory uses, will require high-carbon ferrochrome. In the aviation industry, however, the requirement for low carbon content and high

Table 3-10.–U.S. Bureau of Mines Estimates of Probable Demand for Strategic Metals in the Year 2000

Sector	Chromium		Cobalt		Manganese		Platinum group	
	1,000 tons	(Percent)	1,000 lbs	(Percent)	1,000 tons	(Percent)	1,000 oz	(Percent)
Transportation	170	(22)	10,000	(32)	510	(36)	950	(28)
Construction	160	(20)	0	(0)	300	(21)	240	(7)
Machinery	120	(15)	5,000	(17)	220	(16)	0	(0)
Electrical	90	(12)	4,000	(13)	85	(6)	490	(15)
Refractory	30	(4)	(note 1)	(0)	0	(0)	220	(6)
Chemical	100	(13)	11,000	(35)	75	(5)	820	(24)
Other	110	(14)	1,000	(3)	230	(16)	670	(20)
Total	780	(100)	31,500	(100)	1,420	(100)	3,390	(100)

NOTE 1 Statistics on use of cobalt in glass and ceramics were combined with those on paint and chemical uses in 1983

SOURCE U.S Bureau of Mines, Mineral Commodity Profiles, 1983

purity will mean that the industry will need substantial amounts of low-carbon ferrochrome (6,500 tons of contained chromium in 1995) and chromium metal (3,700 tons in 1995).

- Requirements for PGMs in the electronics sector are likely to be considerably higher than projected by the Bureau of Mines owing to the rapid increase in palladium consumption in ceramic capacitors. Estimated consumption in 1983 of 500,000 troy ounces of palladium already exceed the Bureau of Mines' forecast of 300,000 troy ounces in 2000. Anticipated consumption of 1 million ounces in 1984 and a projected annual growth rate of 20 percent per annum indicate that estimates of PGM requirements for the electronic sector are low and in need of further study.
- Requirements for platinum, palladium, and rhodium in the automotive sector do not include PGMs contained in the catalytic converters of imported automobiles, Other factors, including the use of platinum-containing particulate traps will also result in higher consumption of PGMs. Estimated requirements for PGMs in catalytic converters in 1995, made by Sierra Research for OTA, are for 1.4 million troy ounces, almost 50 percent greater than the Bureau of Mines' forecast.
- Estimated consumption of cobalt, chromium, and PGMs do not distinguish between primary metal, produced directly from mined ore, and secondary metal obtained from prompt industrial and obsolete scrap.
- Estimates of future manganese requirements are based on the assumption that the ratio of manganese to iron used in steelmaking will decline by only 10 percent by the year 2000.

Although it is difficult to estimate the specific quantities of strategic metals that can be deemed to be essential, it is possible to identify the principal applications that are essential to the United States and that use chromium, cobalt, manganese, and PGMs to fulfill their functions. These applications, and their strategic materials requirements, are summarized below,

Superalloy

Chromium, in the form of both chromium metal and low-carbon ferrochromium, is an essential element in superalloy. In addition, cobalt is currently used in a number of superalloy, particularly in the applications of highest temperature and stress. To meet future requirements for superalloy in gas turbine engines, jet aircraft, and other applications, the chromium requirements for 1995 are estimated to be 3,700 tons of chromium metal, 6,500 tons of low-carbon ferrochrome, and 8.3 million pounds of cobalt. Similar estimates for the year 2010 are 6,800 tons of chromium metal, 12,000 tons of chromium in ferrochrome, and 13 million pounds of cobalt.

Stainless Steel for Construction

Stainless and other alloy steels are used in the energy and chemical process industries to provide resistance to high temperature, corrosion, and oxidation and to limit contamination of chemicals that could occur from the use of less resistant materials in tanks, piping, and process vessels. In 1979, the Department of Commerce estimated chromium requirements for the energy industry at 27,000 tons in 1990 and 33,000 tons in 2000. NMAB estimates were lower (see table 3-4). The bulk of the chromium will be used as high-carbon ferrochrome, but a small percentage of the applications will be in special alloys that require low-carbon ferrochrome or chromium metal.

Automobiles

In automotive applications, the catalytic converter accounts for about 85 percent of the essential uses of chromium and all of the uses of PGMs. The estimated essential requirements for chromium in automotive applications will be 15,000 short tons in 1990 and 16,000 short tons in 1995. Requirements for PGMs are 1.3 million troy ounces in 1990 and 1.4 million troy ounces in 1995. Estimates for both chromium and PGMs are for all automobiles sold in the United States. Direct U.S. requirements for chromium and platinum metal will be reduced by the degree of market penetration made by foreign automobiles.

Cemented Carbides

Cemented carbides are one of the most essential applications of cobalt. There are no acceptable alternatives to cobalt for binding the carbide particles together, so virtually all cobalt in this use is essential. Estimates for 1995 cobalt requirements in cemented carbides are about 1.3 million pounds, rising to about 2. I million pounds in 2010.

Industrial Catalysts

The use of catalysts in the petroleum and chemical industries is expected to grow at a high rate, more than doubling by the year 2000. Although in some cases there are alternatives to the processes that utilize cobalt and PGM containing catalysts, once facilities are constructed there is little opportunity to substitute an alternative process that reduces cobalt or PGM demand unless large investments are made to modify plant designs.

Manganese in Steelmaking

Manganese is essential to the manufacture of steel. The amount that is essential to the United States depends on the essential needs for steel, the mix of steel products (i.e., carbon steel; alloy steel; high-strength, low-alloy steel; and stainless steels), the sulfur content of the raw steel, and the efficiency of the steelmaking process.

Palladium in Electronic Components

Over the next few years, the use of palladium alloys as electrodes in ceramic capacitors will cause palladium consumption in the electronic sector to increase to a level substantially greater than indicated by the Bureau of Mines' estimates. However, the development of new technologies, which will be spurred by the limited availability of palladium relative to the needs of the manufacturers of ceramic capacitors, will then cause a decline in the demand for palladium,